Chapter 6

Inventory Control Models

To accompany
Quantitative Analysis for Management, Eleventh Edition,
by Render, Stair, and Hanna
Power Point slides created by Brian Peterson

Learning Objectives

After completing this chapter, students will be able to:

1. Understand the importance of inventory control and ABC analysis.
2. Use the economic order quantity (EOQ) to determine how much to order.
3. Compute the reorder point (ROP) in determining when to order more inventory.
4. Handle inventory problems that allow quantity discounts or non-instantaneous receipt.

Learning Objectives

After completing this chapter, students will be able to:

5. Understand the use of safety stock.
6. Describe the use of material requirements planning in solving dependent-demand inventory problems.
7. Discuss just-in-time inventory concepts to reduce inventory levels and costs.
8. Discuss enterprise resource planning systems.

Chapter Outline

6.1 Introduction
6.2 Importance of Inventory Control
6.3 Inventory Decisions
6.4 Economic Order Quantity: Determining How Much to Order
6.5 Reorder Point: Determining When to Order
6.6 EOQ Without the Instantaneous Receipt Assumption
6.7 Quantity Discount Models
6.8 Use of Safety Stock

Chapter Outline

Introduction

- Inventory is an expensive and important asset to many companies.
- Inventory is any stored resource used to satisfy a current or future need.
- Common examples are raw materials, work-in-process, and finished goods.
- Most companies try to balance high and low inventory levels with cost minimization as a goal.
  - Lower inventory levels can reduce costs.
  - Low inventory levels may result in stockouts and dissatisfied customers.

Introduction

- All organizations have some type of inventory control system.
- Inventory planning helps determine what goods and/or services need to be produced.
- Inventory planning helps determine whether the organization produces the goods or services or whether they are purchased from another organization.
- Inventory planning also involves demand forecasting.

Introduction

Inventory planning and control

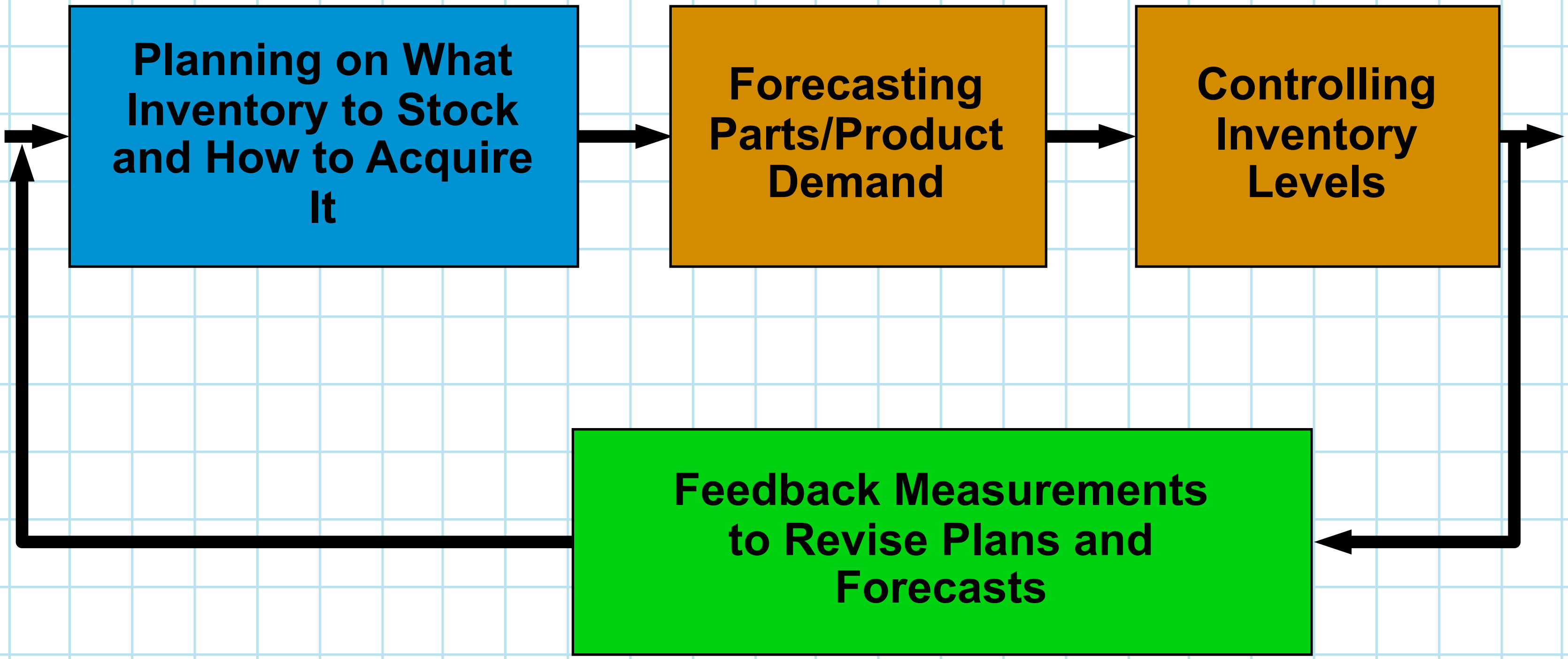


Figure 6.1

Importance of Inventory Control

- Five uses of inventory:
  - The decoupling function
  - Storing resources
  - Irregular supply and demand
  - Quantity discounts
  - Avoiding stockouts and shortages
- Decouple manufacturing processes.
  - Inventory is used as a buffer between stages in a manufacturing process.
  - This reduces delays and improves efficiency.

Importance of Inventory Control

- Storing resources.
  - Seasonal products may be stored to satisfy off-season demand.
  - Materials can be stored as raw materials, work-in-process, or finished goods.
  - Labor can be stored as a component of partially completed subassemblies.
- Compensate for irregular supply and demand.
  - Demand and supply may not be constant over time.
  - Inventory can be used to buffer the variability.

Importance of Inventory Control

- Take advantage of quantity discounts.
  - Lower prices may be available for larger orders.
  - Extra costs associated with holding more inventory must be balanced against lower purchase price.
- Avoid stockouts and shortages.
  - Stockouts may result in lost sales.
  - Dissatisfied customers may choose to buy from another supplier.

Inventory Decisions

- There are two fundamental decisions in controlling inventory:
  - How much to order.
  - When to order.
- The major objective is to minimize total inventory costs.
- Common inventory costs are:
  - Cost of the items (purchase or material cost).
  - Cost of ordering.
  - Cost of carrying, or holding, inventory.
  - Cost of stockouts.

Inventory Cost Factors

ORDERING COST FACTORS	CARRYING COST FACTORS
Developing and sending purchase orders	Cost of capital
Processing and inspecting incoming inventory	Taxes
Bill paying	Insurance
Inventory inquiries	Spoilage
Utilities, phone bills, and so on, for the purchasing department	Theft
Salaries and wages for the purchasing department employees	Obsolescence
Supplies, such as forms and paper, for the purchasing department	Salaries and wages for warehouse employees
	Utilities and building costs for the warehouse
	Supplies, such as forms and paper, for the warehouse

Table 6.1

Inventory Cost Factors

- Ordering costs are generally independent of order quantity.
  - Many involve personnel time.
  - The amount of work is the same no matter the size of the order.
- Carrying costs generally varies with the amount of inventory, or the order size.
  - The labor, space, and other costs increase as the order size increases.
- The actual cost of items purchased can vary if there are quantity discounts available.

Economic Order Quantity

- The ***economic order quantity*** (***EOQ***) model is one of the oldest and most commonly known inventory control techniques.
- It is easy to use but has a number of important assumptions.
- Objective is to minimize total cost of inventory.

Economic Order Quantity

Assumptions:

1. **Demand is known and constant.**
2. **Lead time is known and constant.**
3. **Receipt of inventory is instantaneous.**
4. **Purchase cost per unit is constant throughout the year.**
5. **The only variable costs are the cost of placing an order, *ordering cost*, and the cost of holding or storing inventory over time, *holding* or *carrying cost*, and these are constant throughout the year.**
6. **Orders are placed so that stockouts or shortages are avoided completely.**

Inventory Usage Over Time

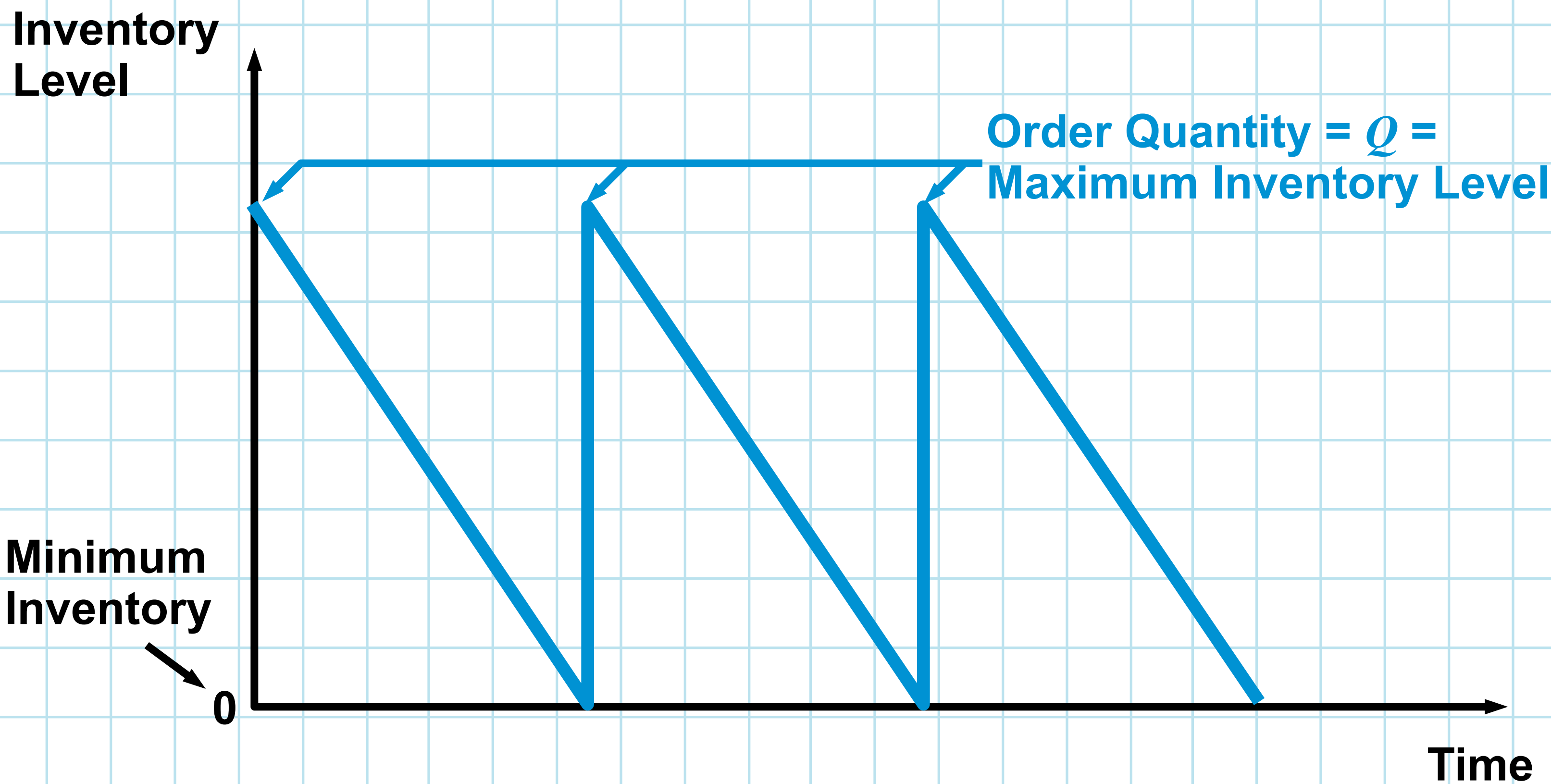


Figure 6.2

Inventory Costs in the EOQ Situation

Computing Average Inventory

$$\text{Average inventory level} = \frac{Q}{2}$$

	INVENTORY LEVEL		
DAY	BEGINNING	ENDING	AVERAGE
April 1 (order received)	10	8	9
April 2	8	6	7
April 3	6	4	5
April 4	4	2	3
April 5	2	0	1

Maximum level April 1 = 10 units
Total of daily averages = 9 + 7 + 5 + 3 + 1 = 25
Number of days = 5
Average inventory level = 25/5 = 5 units

Table 6.2

Inventory Costs in the *EOQ* Situation

Mathematical equations can be developed using:

Q = number of pieces to order
EOQ = Q^* = optimal number of pieces to order
D = annual demand in units for the inventory item
C_o = ordering cost of each order
C_h = holding or carrying cost per unit per year

$$\text{Annual ordering cost} = \begin{pmatrix}\text{Number of}\\ \text{orders placed}\\ \text{per year}\end{pmatrix} \times \begin{pmatrix}\text{Ordering}\\ \text{cost per}\\ \text{order}\end{pmatrix}$$

$$= \frac{D}{Q} C_o$$

Inventory Costs in the EOQ Situation

Mathematical equations can be developed using:

Q = number of pieces to order
EOQ = Q^* = optimal number of pieces to order
D = annual demand in units for the inventory item
C_o = ordering cost of each order
C_h = holding or carrying cost per unit per year

$$\text{Annual holding cost} = \begin{pmatrix}\text{Average}\\ \text{inventory}\end{pmatrix} \times \begin{pmatrix}\text{Carrying}\\ \text{cost per unit}\\ \text{per year}\end{pmatrix}$$

$$= \frac{Q}{2} C_h$$

Inventory Costs in the EOQ Situation

Total Cost as a Function of Order Quantity

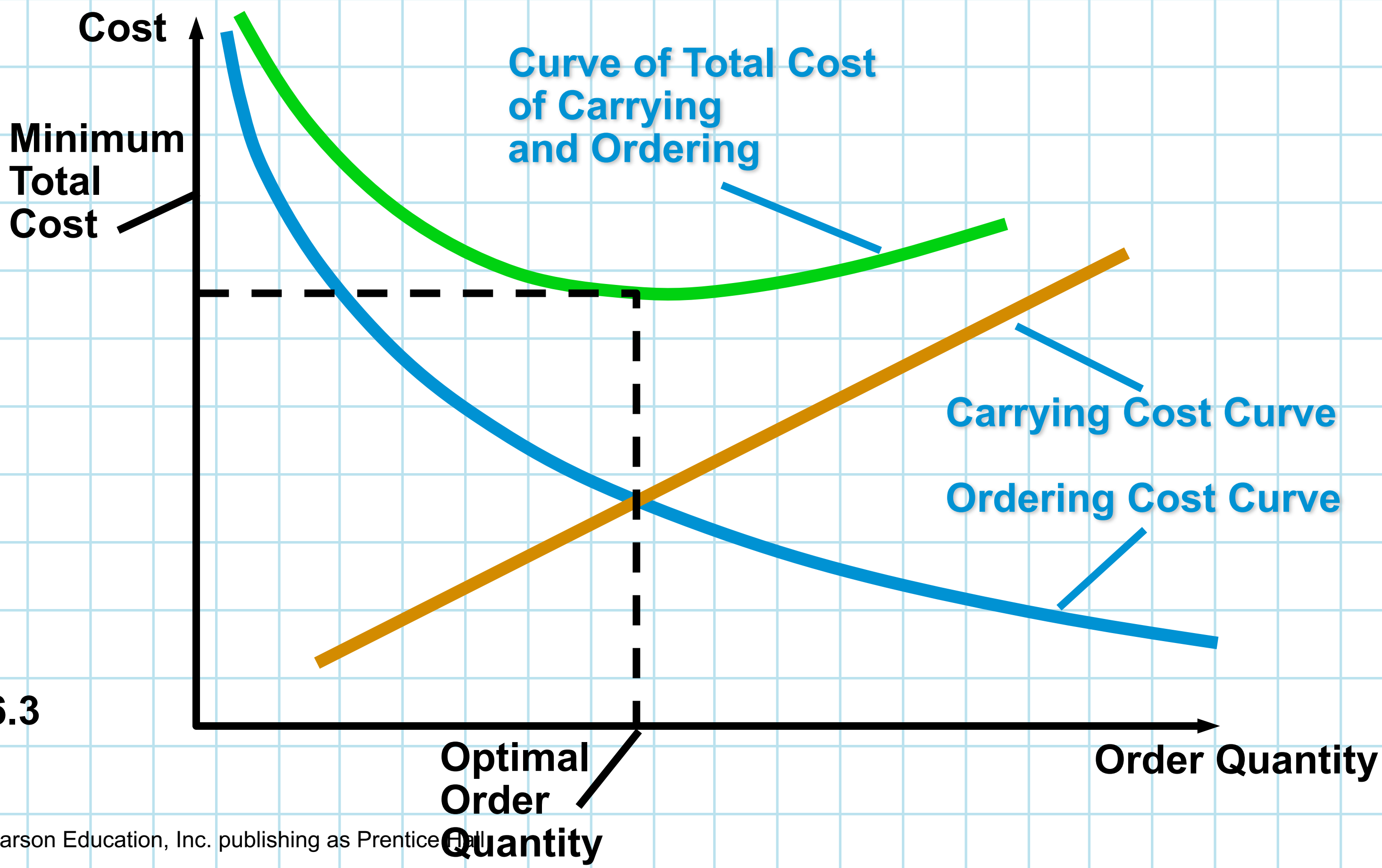


Figure 6.3

Finding the EOQ

According to the graph, when the EOQ assumptions are met, total cost is minimized when annual ordering cost equals annual holding cost.

$$\frac{D}{Q}C_o = \frac{Q}{2}C_h$$

Solving for Q

$$2DC_o = Q^2 C_h$$

$$\frac{2DC_o}{C_h} = Q^2$$

$$\sqrt{\frac{2DC_o}{C_h}} = Q = \text{EOQ} = Q^*$$

Economic Order Quantity (EOQ) Model

Summary of equations:

$$\text{Annual ordering cost} = \frac{D}{Q} C_o$$

$$\text{Annual holding cost} = \frac{Q}{2} C_h$$

$$\text{EOQ} = Q^* = \sqrt{\frac{2DC_o}{C_h}}$$

Sumco Pump Company

- Sumco Pump Company sells pump housings to other companies.
- The firm would like to reduce inventory costs by finding optimal order quantity.
  - Annual demand = 1,000 units
  - Ordering cost = $10 per order
  - Average carrying cost per unit per year = $0.50

$$Q^* = \sqrt{\frac{2DC_o}{C_h}} = \sqrt{\frac{2(1{,}000)(10)}{0.50}} = \sqrt{40{,}000} = 200 \text{ units}$$

Sumco Pump Company

Total annual cost = Order cost + Holding cost

$$TC = \frac{D}{Q}C_o + \frac{Q}{2}C_h$$

$$= \frac{1{,}000}{200}(10) + \frac{200}{2}(0.5)$$

$$= \$50 + \$50 = \$100$$

Sumco Pump Company

Input Data and Excel QM formulas for the Sumco Pump Company Example

	A	B	C	D
1	**Sumco Pump Company**			
2				
3	**Inventory**	**Economic Order Quantity Model**		
4	Enter the data in the shaded area			
5				
6				
7	**Data**			
8	Demand rate, D	1000		
9	Setup/order cost, S	10		
10	Holding cost, H	0.5	(fixed amount)	
11	Unit Price, P			
12				
13	**Results**			
14	**Optimal Order Quantity, Q***	=SQRT(2*B8*B9/B10)		
15	**Maximum Inventory**	=B14		
16	**Average Inventory**	=B14/2		
17	**Number of Orders**	=B8/B14		
18				
19	**Holding cost**	=B16*B10		
20	**Setup cost**	=B17*B9		
21				
22	**Unit costs**	=B11*B8		
23	Total cost, T_c	=B19+B20+B22		
24				

Enter demand rate, setup/ordering cost, holding cost, and unit price.

If unit price is available, it is entered here.

On input screen, you may specify whether the holding cost is fixed amount or a percentage of the unit (purchase) cost.

Total unit (purchase) cost is given here.

Program 6.1A

Sumco Pump Company

Excel QM Solution for the Sumco Pump Company Example

	A	B	C	D	E	F
1	**Sumco Pump Company**					
2						
3	**Inventory**	**Economic Order Quantity Model**				
4	Enter the data in the shaded area					
5						
6						
7	**Data**					
8	Demand rate, D	1000				
9	Setup/order cost, S	10				
10	Holding cost, H	0.5	(fixed amount)			
11	Unit Price, P					
12						
13	**Results**					
14	**Optimal Order Quantity, Q***	**200**				
15	**Maximum Inventory**	**200**				
16	**Average Inventory**	**100**				
17	**Number of Orders**	**5**				
18						
19	**Holding cost**	**$50.00**				
20	**Setup cost**	**$50.00**				
21						
22	**Unit costs**	**$0.00**				
23	Total cost, T_c	$100.00				
24						

Total cost includes holding cost, ordering/setup cost, and unit/purchase cost if the unit cost is input.

Program 6.1B

Purchase Cost of Inventory Items

- Total inventory cost can be written to include the cost of purchased items.
- Given the EOQ assumptions, the annual purchase cost is constant at $D \times C$ no matter the order policy, where
  - C is the purchase cost per unit.
  - D is the annual demand in units.
- At times it may be useful to know the average dollar level of inventory:

$$\text{Average dollar level} = \frac{(CQ)}{2}$$

Purchase Cost of Inventory Items

- Inventory carrying cost is often expressed as an annual percentage of the unit cost or price of the inventory.
- This requires a new variable.

$$I = \begin{pmatrix} \text{Annual inventory holding charge as} \\ \text{a percentage of unit price or cost} \end{pmatrix}$$

- The cost of storing inventory for one year is then

$$C_h = IC$$

thus, $$Q^* = \sqrt{\frac{2DC_o}{IC}}$$

Sensitivity Analysis with the EOQ Model

- The EOQ model assumes all values are know and fixed over time.
- Generally, however, some values are estimated or may change.
- Determining the effects of these changes is called ***sensitivity analysis.***
- Because of the square root in the formula, changes in the inputs result in relatively small changes in the order quantity.

$$\text{EOQ} = \sqrt{\frac{2DC_o}{C_h}}$$

Sensitivity Analysis with the *EOQ* Model

- In the Sumco Pump example:

$$\text{EOQ} = \sqrt{\frac{2(1{,}000)(10)}{0.50}} = 200 \text{ units}$$

- If the ordering cost were increased four times from \$10 to \$40, the order quantity would only double

$$\text{EOQ} = \sqrt{\frac{2(1{,}000)(40)}{0.50}} = 400 \text{ units}$$

- In general, **the EOQ changes by the square root of the change to any of the inputs**.

Reorder Point: Determining When To Order

- Once the order quantity is determined, the next decision is ***when to order.***
- The time between placing an order and its receipt is called the ***lead time*** (L) or ***delivery time.***
- When to order is generally expressed as a ***reorder point*** (ROP).

$$\text{ROP} = \begin{pmatrix}\text{Demand}\\ \text{per day}\end{pmatrix} \times \begin{pmatrix}\text{Lead time for a}\\ \text{new order in days}\end{pmatrix}$$

$$= d \times L$$

Procomp's Computer Chips

- **Demand for the computer chip is 8,000 per year.**
- **Daily demand is 40 units.**
- **Delivery takes three working days.**

$$\text{ROP} = d \times L = \textbf{40 units per day} \times \textbf{3 days}$$
$$= \textbf{120 units}$$

- **An order based on the EOQ calculation is placed when the inventory reaches 120 units.**
- **The order arrives 3 days later just as the inventory is depleted.**

Reorder Point Graphs

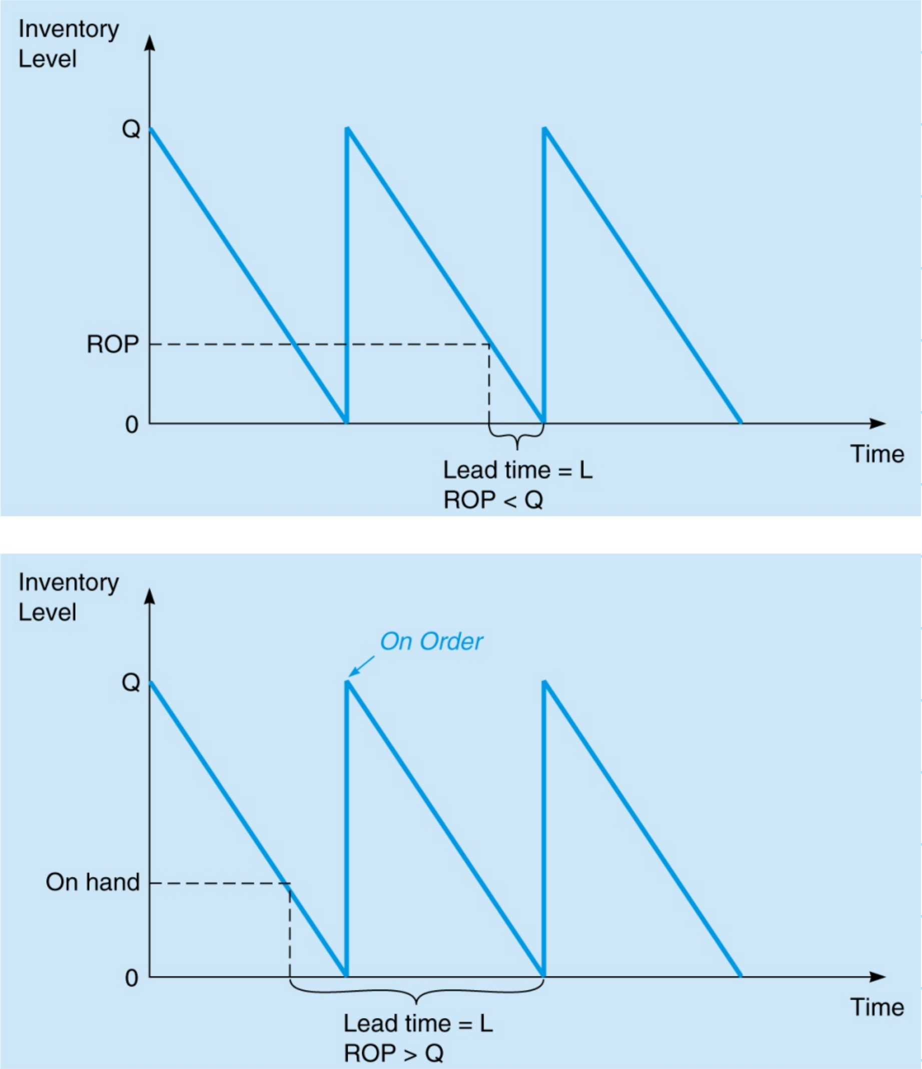


Figure 6.4

EOQ Without The Instantaneous Receipt Assumption

- When inventory accumulates over time, the ***instantaneous receipt*** assumption does not apply.
- Daily demand rate must be taken into account.
- The revised model is often called the ***production run model.***

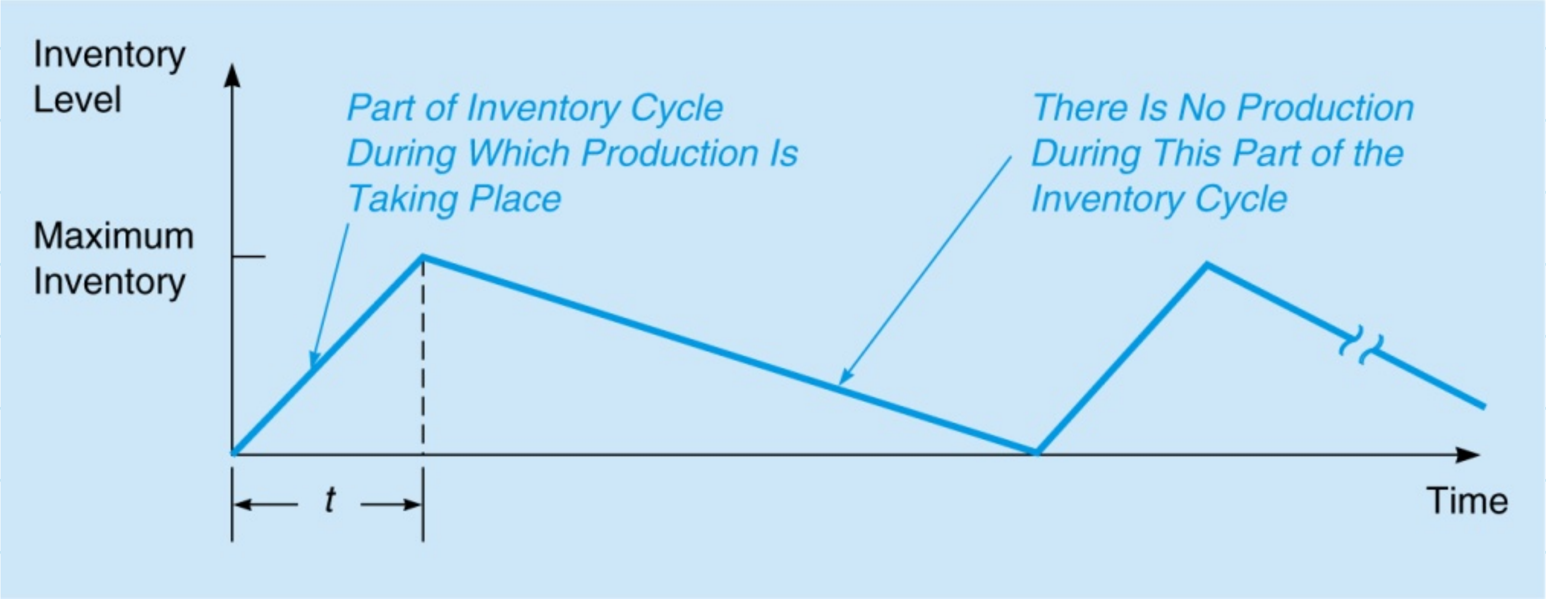


Figure 6.5

Annual Carrying Cost for Production Run Model

- In production runs, ***setup cost*** replaces ordering cost.
- The model uses the following variables:

Q = number of pieces per order, or production run

C_s = setup cost

C_h = holding or carrying cost per unit per year

p = daily production rate

d = daily demand rate

t = length of production run in days

Annual Carrying Cost for Production Run Model

Maximum inventory level

= (Total produced during the production run)
– (Total used during the production run)

= (Daily production rate)(Number of days production)
– (Daily demand)(Number of days production)

= $(pt) - (dt)$

since Total produced $= Q = pt$

we know $t = \dfrac{Q}{p}$

$$\text{Maximum inventory level} = pt - dt = p\frac{Q}{p} - d\frac{Q}{p} = Q\left(1 - \frac{d}{p}\right)$$

Annual Carrying Cost for Production Run Model

Since the average inventory is one-half the maximum:

$$\text{Average inventory} = \frac{Q}{2}\left(1 - \frac{d}{p}\right)$$

and

$$\text{Annual holding cost} = \frac{Q}{2}\left(1 - \frac{d}{p}\right)C_h$$

Annual Setup Cost for Production Run Model

Setup cost replaces ordering cost when a product is produced over time.

$$\text{Annual setup cost} = \frac{D}{Q} C_s$$

replaces

$$\text{Annual ordering cost} = \frac{D}{Q} C_o$$

Determining the Optimal Production Quantity

By setting setup costs equal to holding costs, we can solve for the optimal order quantity

Annual holding cost = Annual setup cost

$$\frac{Q}{2}\left(1-\frac{d}{p}\right)C_h = \frac{D}{Q}C_s$$

Solving for Q, we get

$$Q^* = \sqrt{\frac{2DC_s}{C_h\left(1-\frac{d}{p}\right)}}$$

Production Run Model

Summary of equations

$$\text{Annual holding cost} = \frac{Q}{2}\left(1 - \frac{d}{p}\right)C_h$$

$$\text{Annual setup cost} = \frac{D}{Q}C_s$$

$$\text{Optimal production quantity } Q^* = \sqrt{\frac{2DC_s}{C_h\left(1 - \frac{d}{p}\right)}}$$

Brown Manufacturing

Brown Manufacturing produces commercial refrigeration units in batches.

Annual demand = D = 10,000 units
Setup cost = C_s = \$100
Carrying cost = C_h = \$0.50 per unit per year
Daily production rate = p = 80 units daily
Daily demand rate = d = 60 units daily

1. **How many units should Brown produce in each batch?**
2. **How long should the production part of the cycle last?**

Brown Manufacturing Example

1. $$Q^* = \sqrt{\frac{2DC_s}{C_h\left(1-\frac{d}{p}\right)}}$$

$$Q^* = \sqrt{\frac{2\times 10{,}000\times 100}{0.5\left(1-\frac{60}{80}\right)}}$$

$$= \sqrt{\frac{2{,}000{,}000}{0.5\left(\frac{1}{4}\right)}} = \sqrt{16{,}000{,}000}$$

$$= 4{,}000 \text{ units}$$

2. $$\text{Production cycle} = \frac{Q}{p}$$

$$= \frac{4{,}000}{80} = 50 \text{ days}$$

Brown Manufacturing

Excel QM Formulas and Input Data for the Brown Manufacturing Problem

	A	B	C	D	E
1	**Brown Manufacturing**				
2					
3	**Inventory**	Production Order Quantity Model			
4	Enter the data in the shaded area. You may have to do some work to enter the daily				
5					
6	Data				
7	Demand rate, D	10000			
8	Setup cost, S	100			
9	Holding cost, H	0.5	(fixed amount)		
10	Daily production rate, p	80			
11	Daily demand rate, d	60			
12	Unit price, P	0			
13					
14	**Results**				
15	Optimal production quantity, Q*	=SQRT(2*B7*B8/B9)*SQRT(B10/(B10-B11))			
16	Maximum Inventory	=B15*(B10-B11)/B10			
17	Average Inventory	=B16/2			
18	Number of Setups	=B7/B15			
19					
20	Holding cost	=B17*B9			
21	Setup cost	=B18*B8			
22					
23	Unit costs	=B12*B7			
24					
25	Total cost, T_c	=B20+B21+B23			

Enter the demand rate, setup cost, and holding cost. Notice that the holding cost is a fixed dollar amount rather than a percentage of the unit price.

Enter daily production rate and daily demand rate.

Calculate the optimal production quantity.

Calculate the maximum inventory.

Calculate the average number of setups.

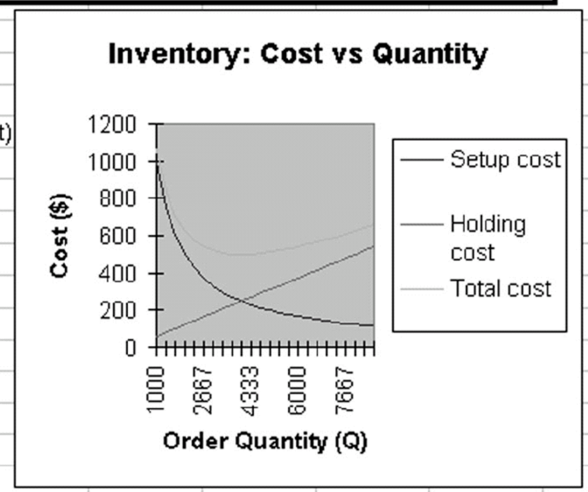
Calculate the annual holding costs based on average inventory and the annual setup cost based on the number of setups.

Program 6.2A

Brown Manufacturing

The Solution Results for the Brown Manufacturing Problem Using Excel QM

	A	B	C
1	**Brown Manufacturing**		
2			
3	**Inventory**	Production Order Quantity Model	
4	Enter the data in the shaded area. You may have to do some work to enter the daily production rate.		
5			
6	Data		
7	Demand rate, D	10000	
8	Setup cost, S	100	
9	Holding cost, H	0.5	(fixed amount)
10	Daily production rate, p	80	
11	Daily demand rate, d	60	
12	Unit price, P	0	
13			
14	**Results**		
15	Optimal production quantity, Q*	4000	
16	Maximum Inventory	1000	
17	Average Inventory	500	
18	Number of Setups	2.5	
19			
20	Holding cost	250	
21	Setup cost	250	
22			
23	Unit costs	0	
24			
25	Total cost, T_c	500	



Program 6.2B

Quantity Discount Models

- Quantity discounts are commonly available.
- The basic EOQ model is adjusted by adding in the purchase or materials cost.

Total cost = Material cost + Ordering cost + Holding cost

$$\text{Total cost} = DC + \frac{D}{Q}C_o + \frac{Q}{2}C_h$$

where

D = annual demand in units

C_o = ordering cost of each order

C = cost per unit

C_h = holding or carrying cost per unit per year

Quantity Discount Models

Because unit cost is now variable,

Holding cost $= C_h = IC$

$I =$ holding cost as a percentage of the unit cost (C)

$$\text{Total cost} = DC + \frac{D}{Q}C_o + \frac{Q}{2}C_h$$

where

D = annual demand in units

C_o = ordering cost of each order

C = cost per unit

C_h = holding or carrying cost per unit per year

Quantity Discount Models

- A typical quantity discount schedule can look like the table below.
- However, buying at the lowest unit cost is not always the best choice.

DISCOUNT NUMBER	DISCOUNT QUANTITY	DISCOUNT (%)	DISCOUNT COST ($)
1	0 to 999	0	5.00
2	1,000 to 1,999	4	4.80
3	2,000 and over	5	4.75

Table 6.3

Quantity Discount Models

Total cost curve for the quantity discount model

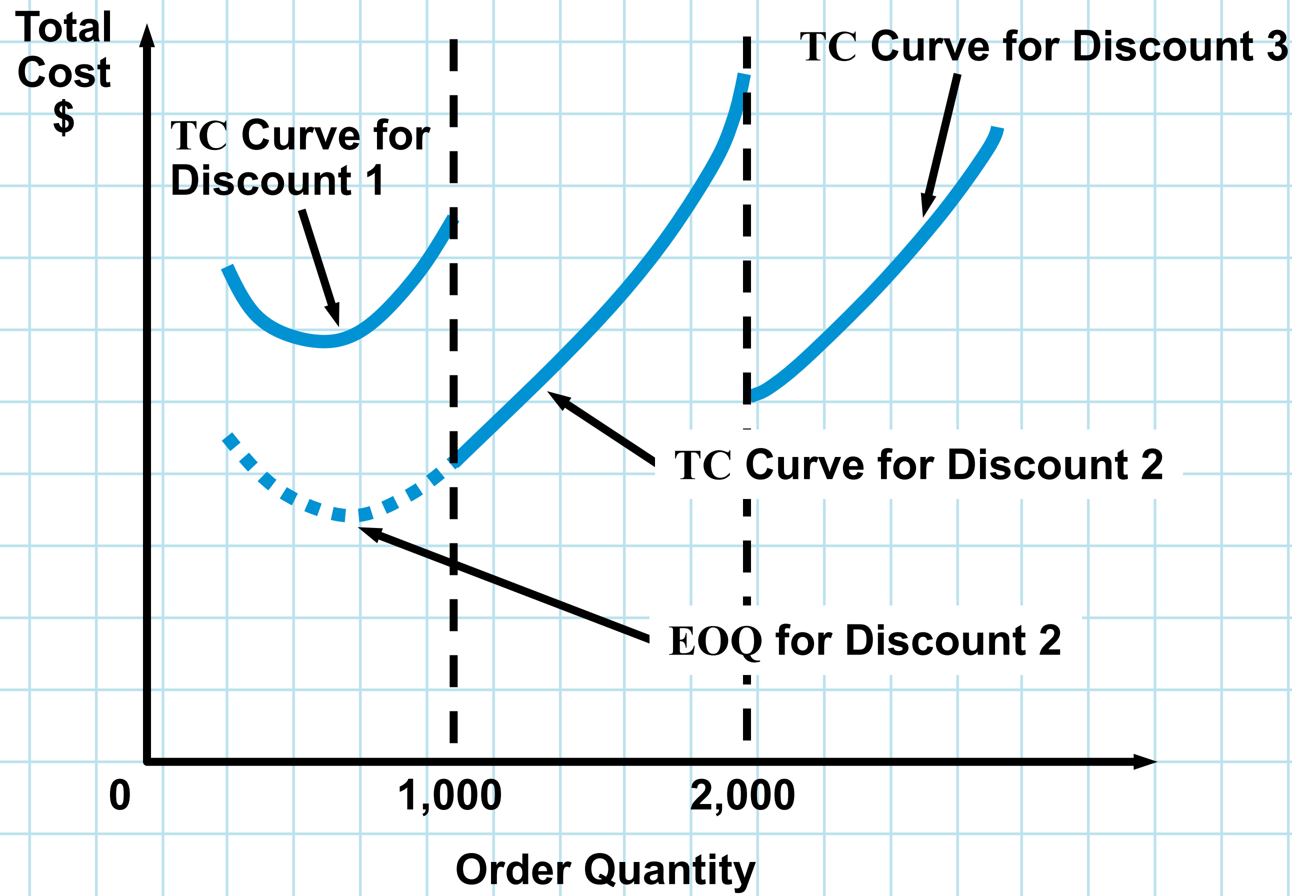


Figure 6.6

Brass Department Store

- Brass Department Store stocks toy race cars.
- Their supplier has given them the quantity discount schedule shown in Table 6.3.
  - Annual demand is 5,000 cars, ordering cost is $49, and holding cost is 20% of the cost of the car
- The first step is to compute EOQ values for each discount.

$$EOQ_1 = \sqrt{\frac{(2)(5{,}000)(49)}{(0.2)(5.00)}} = 700 \text{ cars per order}$$

$$EOQ_2 = \sqrt{\frac{(2)(5{,}000)(49)}{(0.2)(4.80)}} = 714 \text{ cars per order}$$

$$EOQ_3 = \sqrt{\frac{(2)(5{,}000)(49)}{(0.2)(4.75)}} = 718 \text{ cars per order}$$

Brass Department Store Example

- The second step is adjust quantities below the allowable discount range.
- The EOQ for discount 1 is allowable.
- The EOQs for discounts 2 and 3 are outside the allowable range and have to be adjusted to the smallest quantity possible to purchase and receive the discount:

$$Q_1 = 700$$
$$Q_2 = 1{,}000$$
$$Q_3 = 2{,}000$$

Brass Department Store

The third step is to compute the total cost for each quantity.

DISCOUNT NUMBER	UNIT PRICE (C)	ORDER QUANTITY (Q)	ANNUAL MATERIAL COST ($) = DC	ANNUAL ORDERING COST ($) = $(D/Q)C_o$	ANNUAL CARRYING COST ($) = $(Q/2)C_h$	TOTAL ($)
1	$5.00	700	25,000	350.00	350.00	25,700.00
2	4.80	1,000	24,000	245.00	480.00	24,725.00
3	4.75	2,000	23,750	122.50	950.00	24,822.50

The final step is to choose the alternative with the lowest total cost.

Table 6.4

Brass Department Store

Excel QM's Formulas and the Input Data for the Brass Department Store Quantity Discount Problem

	A	B	C	D	E	F
1	**Brass Department Store**					
2						
3	**Inventory**	Quantity Discount Model				
4						
5	Data					
6	Demand rate, D	5000				
7	Setup cost, S	49				
8	Holding cost %, I	20%				
9						
10		Range 1	Range 2	Range 3		
11	Minimum quantity	0	1000	2000		
12	Unit Price, P	5	4.8	4.75		
13						
14	**Results**					
15		=B10	=C10	=D10		
16	Q* (Square root formula)	=SQRT(2*$B$6*$B$7/($B$8*B12))	=SQRT(2*$B$6*$B	=SQRT(2*$B$6*$B$7/($B$8*D12))		
17	Order Quantity	=IF(B16>=B11,B16,B11)	=IF(C16>=C11,C1	=IF(D16>=D11,D16,D11)	=	
18						
19	Holding cost	=B17*$B$8*B12/2	=C17*$B$8*C12/2	=D17*$B$8*D12/2		
20	Setup cost	=$B$7*$B$6/B17	=$B$7*$B$6/C17	=$B$7*$B$6/D17		
21						
22	Unit costs	=B12*$B$6	=C12*$B$6	=D12*$B$6		
23						
24	Total cost, T_c	=B19+B20+B22	=C19+C20+C22	=D19+D20+D22	minimum	=MIN(B24:D24)
25	Optimal Order Quantity	=IF(B24=$F$24,B17,"")	=IF(C24=$F$24,C1	=IF(D24=$F$24,D17,"")		
26						
27						
28						

Enter demand rate, setup cost, and holding cost.

Enter the quantity discount schedule of quantities and unit prices for each price break.

Compute the order quantities for each price break and adjust them upward if necessary.

Compute holding, setup, and unit cost for each price break.

Compute the total cost for each price break.

Determine the optimal order quantity by finding the order quantity that minimizes total costs.

Program 6.3A

Brass Department Store

Excel QM's Solution to the Brass Department Store Problem

	A	B	C	D	E	F	G	H
1	**Brass Department Store**							
2								
3	**Inventory**	Quantity Discount Model						
4								
5	Data							
6	Demand rate, D	5000						
7	Setup cost, S	49						
8	Holding cost %, I	20%						
9								
10		Range 1	Range 2	Range 3				
11	Minimum quantity	0	1000	2000				
12	Unit Price, P	5	4.8	4.75				
13								
14	**Results**							
15		Range 1	Range 2	Range 3				
16	Q* (Square root formula)	700	714.434508	718.184846				
17	Order Quantity	700	1000	2000		=		
18								
19	Holding cost	$350.00	$480.00	$950.00				
20	Setup cost	$350.00	$245.00	$122.50				
21								
22	Unit costs	$25,000.00	$24,000.00	$23,750.00				
23								
24	Total cost, T_c	$25,700.00	$24,725.00	$24,822.50	minimum	$24,725.00		
25	Optimal Order Quantity		1000					

Program 6.3B

Use of Safety Stock

- **If demand or the lead time are uncertain, the exact ROP will not be known with certainty.**
- **To prevent *stockouts*, it is necessary to carry extra inventory called *safety stock.***
- **Safety stock can prevent stockouts when demand is unusually high.**
- **Safety stock can be implemented by adjusting the ROP.**

Use of Safety Stock

- The basic ROP equation is

$$\text{ROP} = d \times L$$

d = daily demand (or average daily demand)

L = order lead time or the number of working days it takes to deliver an order (or average lead time)

- A safety stock variable is added to the equation to accommodate uncertain demand during lead time

$$\text{ROP} = d \times L + SS$$

where

SS = safety stock

Use of Safety Stock

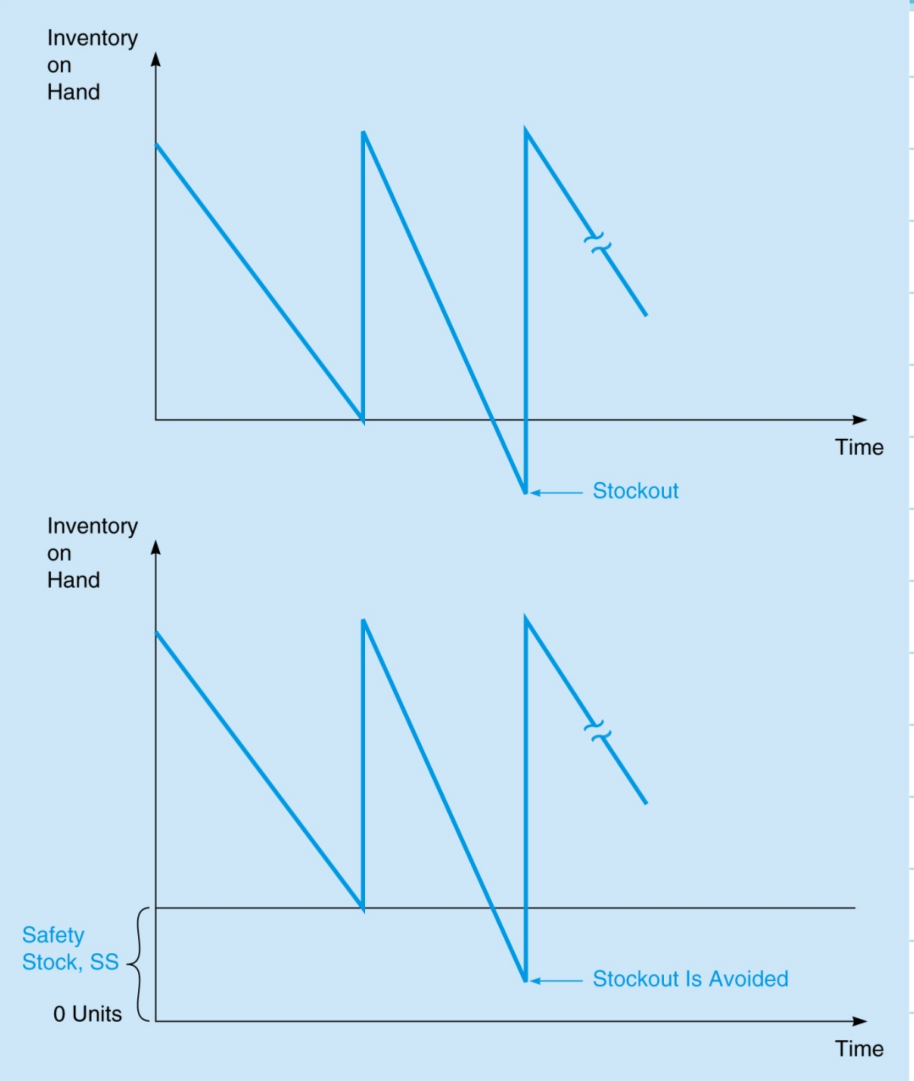


Figure 6.7

ROP with Known Stockout Costs

- With a fixed EOQ and an ROP for placing orders, stockouts can only occur during lead time.
- Our objective is to find the safety stock quantity that will minimize the total of stockout cost and holding cost.
- We need to know the stockout cost per unit and the probability distribution of demand during lead time.
- Estimating stockout costs can be difficult as there may be direct and indirect costs.

Safety Stock with Unknown Stockout Costs

- There are many situations when stockout costs are unknown.
- An alternative approach to determining safety stock levels is to use a ***service level***.
- A service level is the percent of time you will not be out of stock of a particular item.

Service level = 1 – Probability of a stockout

or

Probability of a stockout = 1 – Service level

Safety Stock with the Normal Distribution

ROP = (Average Demand During Lead Time) + $Z\sigma_{dLT}$

Safety Stock = $Z\sigma_{dLT}$

Where:

Z = number of standard deviations for a given service level
σ_{dLT} = standard deviation of demand during lead time

Hinsdale Company

- Inventory demand during lead time is normally distributed.
- Mean demand during lead time is 350 units with a standard deviation of 10.
- The company wants stockouts to occur only 5% of the time.

μ = Mean demand = 350

σ_{dLT} = Standard deviation = 10

X = Mean demand + Safety stock

SS = Safety stock = $X - \mu = Z\sigma$

$$Z = \frac{X - \mu}{\sigma}$$

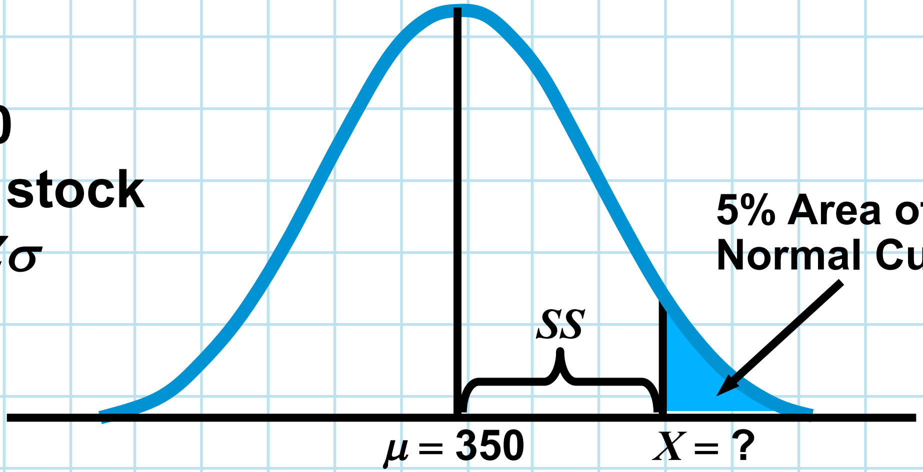


Figure 6.8

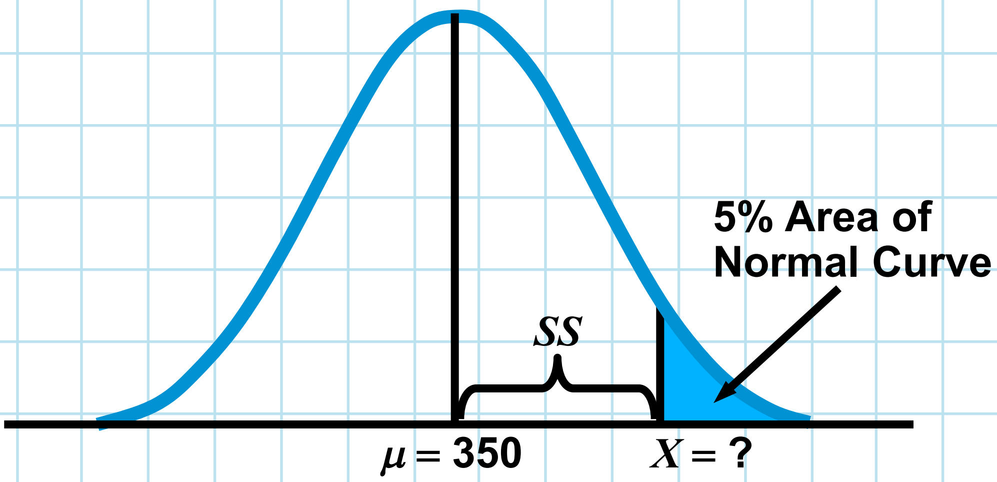
Hinsdale Company Example

- From Appendix A we find $Z = 1.65 = \dfrac{X - \mu}{\sigma} = \dfrac{SS}{\sigma}$
- Solving for safety stock:

$$SS = 1.65(10) = 16.5 \text{ units, or } 17 \text{ units}$$

$$X = ROP = 350 + 16.5 = 366.5 \text{ units}$$

Figure 6.9



Hinsdale Company

- Different safety stock levels will be generated for different service levels.
- However, the relationship is not linear.
  - You should be aware of what a service level is costing in terms of carrying the safety stock in inventory.
- The relationship between Z and safety stock can be developed as follows:

1. We know that $Z = \dfrac{X - \mu}{\sigma}$
2. We also know that $SS = X - \mu$
3. Thus $Z = \dfrac{SS}{\sigma}$
4. So we have

$$SS = Z\sigma$$
$$= Z(10)$$

Hinsdale Company

Safety Stock at different service levels

SERVICE LEVEL (%)	*Z* VALUE FROM NORMAL CURVE TABLE	SAFETY STOCK (UNITS)
90	1.28	12.8
91	1.34	13.4
92	1.41	14.1
93	1.48	14.8
94	1.55	15.5
95	1.65	16.5
96	1.75	17.5
97	1.88	18.8
98	2.05	20.5
99	2.33	23.3
99.99	3.72	37.2

Table 6.5

Hinsdale Company

Service level versus annual carrying costs

This graph was developed for a specific case, but the general shape of the curve is the same for all service-level problems.

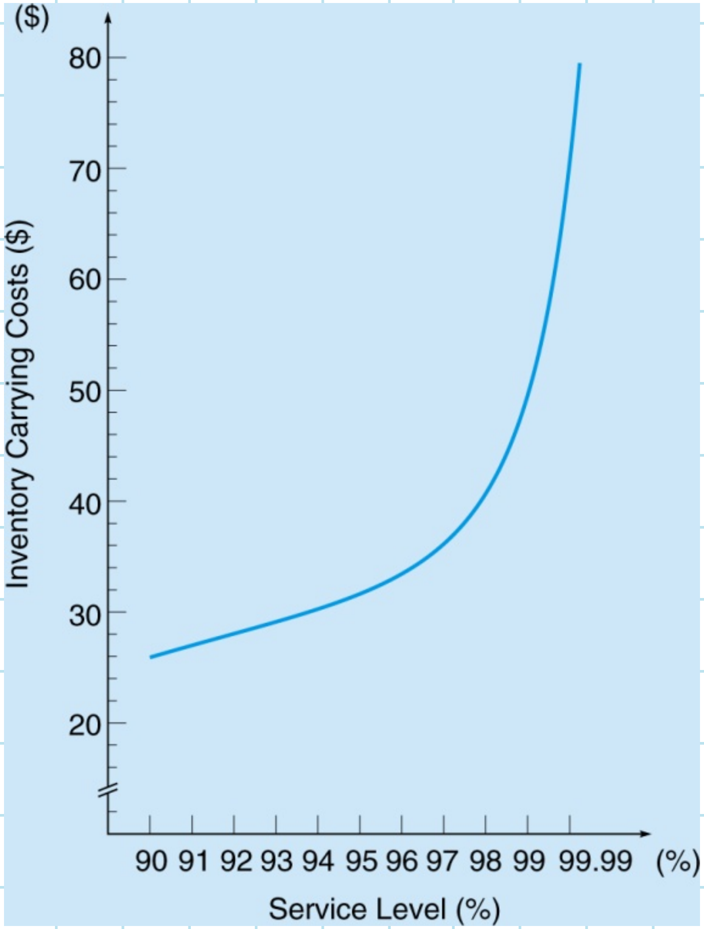


Figure 6.9

Calculating Lead Time Demand and Standard Deviation

- There are three situations to consider:
  - Demand is variable but lead time is constant.
  - Demand is constant but lead time is variable.
  - Both demand and lead time are variable.

Calculating Lead Time Demand and Standard Deviation

Demand is variable but lead time is constant:

$$ROP = \bar{d}L + Z(\sigma_d\sqrt{L})$$

Where:

$$\bar{d} = average\ daily\ demand$$

$$\sigma_d = standard\ deviation\ of\ daily\ demand$$

$$L = lead\ time\ in\ days$$

Calculating Lead Time Demand and Standard Deviation

Demand is constant but lead time is variable:

$$ROP = d\bar{L} + Z(d\sigma_L)$$

Where:

$$\bar{L} = average\ lead\ time$$

$$\sigma_L = standard\ deviation\ of\ lead\ time$$

$$d = daily\ demand$$

Calculating Lead Time Demand and Standard Deviation

Both demand and lead time are variable.

$$ROP = \overline{dL} + Z\left(\sqrt{\overline{L}\sigma_d^2 + \overline{d}^2\sigma_L^2}\right)$$

Notice that this is the most general case and that the other two cases can be derived from this formula.

Hinsdale Company

Suppose for product SKU F5402, daily demand is normally distributed, with a mean of 15 units and a standard deviation of 3. Lead time is exactly 4 days. To maintain a 97% service level, what is the ROP, and how much safety stock should be carried?

$$ROP = \bar{d}L + Z(\sigma_d\sqrt{L})$$

ROP = 15(4)+1.88(3*2)
= 60 + 11.28
=71.28

So the average demand during lead time is 60 units, and safety stock is 11.28 units.

Hinsdale Company

Suppose for product SKU B7319, daily demand is constant at 25 units per day, but lead time is normally distributed, with a mean of 6 days and a standard deviation of 3. To maintain a 98% service level, what is the ROP?

$$ROP = d\bar{L} + Z(d\sigma_L)$$

ROP = 25(6)+2.05(25*3)
= 150+153.75
=303.75

So the average demand during lead time is 150 units, and safety stock is 153.75 units.

Hinsdale Company

Suppose for product SKU F9004, daily demand is normally distributed, with a mean of 20 units and a standard deviation of 4. Lead time is normally distributed, with a mean of 5 days and a standard deviation of 2 days. To maintain a 94% service level, what is the ROP?

$$ROP = \overline{dL} + Z\left(\sqrt{\bar{L}\sigma_d^2 + \bar{d}^2\sigma_L^2}\right)$$

$$ROP = 20(5) + 1.55\left(\sqrt{5(16) + 400(4)}\right)$$

ROP = 100+1.55(40.99)
= 163.53

Calculating Annual Holding Cost with Safety Stock

- Under standard assumptions of EOQ, average inventory is just $Q/2$.
- So annual holding cost is: $(Q/2)*C_h$.
- This is not the case with safety stock because safety stock is not meant to be drawn down.

Calculating Annual Holding Cost with Safety Stock

Total annual holding cost = holding cost of regular inventory + holding cost of safety stock

$$THC = \frac{Q}{2}C_h + (SS)C_h$$

Where:

THC	= total annual holding cost
Q	= order quantity
C_h	= holding cost per unit per year
SS	= safety stock

Excel QM Formulas and Input Data for the Hinsdale Safety Stock Problems

The average demand and standard deviation during the lead time are entered here, if available.

If daily demand is normally distributed but lead time is constant, the data are entered here.

Hinsdale Company Safety Stock

Inventory

Safety stock - Normal distribution

Select a model and then enter the data in the shaded area. The model on

Model: Demand during leadtime and its standard deviat

Data	
Average demand during lead time, μ	350
Standard deviation of σ_{dLT}	10
Service level (% of demand met)	0.95

Results	
Z-value	=NORMSINV(B11)
Safety stock	=B15*B10

Model: Daily demand and its standard deviation are gi

Data	
Average daily demand	15
Standard deviation of daily demand, σ_d	3
Lead time days	4
Service level (% of demand met)	0.97

Results	
Z-value	=NORMSINV(H12)
Average demand during lead time	=H9*H11
Standard deviation of demand during lead time, σ_{dLT}	=H10*SQRT(H11)
	=H15*H17
	=H18+H16

If lead time is normally distributed, data are entered here. If daily demand is constant, enter 0 for the standard deviation.

Models: Either daily demand, lead time or both are varia

Data		
Average daily demand	25	
Standard deviation of daily demand	0	**Enter 0 if demand is constant**
Average lead time (in days)	6	
Standard deviation of lead time, σ_{LT}	3	**Enter 0 if lead time is constant**
Service level (% of demand met)	0.98	

Results	
Z-value	=NORMSINV(B29)
Average demand during lead time	=B27*B25
Standard deviation of demand during lead time, σ_{dLT}	=SQRT(B27*B26^2+B25^2*B28^2)
Safety stock	=B34*B32
Reorder point	=B33+B35

The standard deviation of demand during the lead time is calculated here.

Program 6.4A

Excel QM Solution to the Hinsdale Safety Stock Problem

Hinsdale Company Safety Stock

Inventory — Safety stock - Normal distribution

Select a model and then enter the data in the shaded area. The model on the bottom left represents the 3 models described in the textbook under Other Probabilistic Models

Model: Demand during leadtime and its standard deviation given

Data	
Average demand during lead time, μ	350
Standard deviation of σ_{dLT}	10
Service level (% of demand met)	95.00%

Results	
Z-value	1.64
Safety stock	16.45

Solution to the first Hinsdale example, where standard deviation of demand during lead time was given.

Model: Daily demand and its standard deviation are given

Data	
Average daily demand	15
Standard deviation of daily demand, σ_d	3
Lead time days	4
Service level (% of demand met)	97.00%

Results	
Z-value	1.88
Average demand during lead time	60
Standard deviation of demand during lead time, σ_{dLT}	6.00
Safety stock	11.28
Reorder Point	71.28

Solution to the second Hinsdale, example, where daily demand was normally distributed.

Models: Either daily demand, lead time or both are variable

Data		
Average daily demand	25	
Standard deviation of daily demand	0	Enter 0 if demand is constant
Average lead time (in days)	6	
Standard deviation of lead time, σ_{LT}	3	Enter 0 if lead time is constant
Service level (% of demand met)	98.00%	

Results	
Z-value	2.05
Average demand during lead time	150
Standard deviation of demand during lead time, σ_{dLT}	75.00
Safety stock	154.03
Reorder point	304.03

Solution to the third Hinsdale example, where daily demand was constant but lead time was normally distributed.

Program 6.4B

Single-Period Inventory Models

- Some products have no future value beyond the current period.
- These situations are called ***news vendor*** problems or ***single-period inventory models.***
- Analysis uses marginal profit (MP) and marginal loss (ML) and is called marginal analysis.
- With a manageable number of states of nature and alternatives, discrete distributions can be used.
- When there are a large number of alternatives or states of nature, the normal distribution may be used.

Marginal Analysis with Discrete Distributions

We stock an additional unit only if the expected marginal profit for that unit exceeds the expected marginal loss.

$P =$ probability that demand will be greater than or equal to a given supply (or the probability of selling at least one additional unit).

$1 - P =$ probability that demand will be less than supply (or the probability that one additional unit will not sell).

Marginal Analysis with Discrete Distributions

- The expected marginal profit is $P(\text{MP})$.
- The expected marginal loss is $(1 - P)(\text{ML})$.
- The optimal decision rule is to stock the additional unit if:

$$P(\text{MP}) \geq (1 - P)\text{ML}$$

- With some basic manipulation:

$$P(\text{MP}) \geq \text{ML} - P(\text{ML})$$
$$P(\text{MP}) + P(\text{ML}) \geq \text{ML}$$
$$P(\text{MP} + \text{ML}) \geq \text{ML}$$

or

$$P \geq \frac{\text{ML}}{\text{ML} + \text{MP}}$$

Steps of Marginal Analysis with Discrete Distributions

1. Determine the value of $\dfrac{\text{ML}}{\text{ML} + \text{MP}}$ for the problem.
2. Construct a probability table and add a cumulative probability column.
3. Keep ordering inventory as long as the probability (P) of selling at least one additional unit is greater than $\dfrac{\text{ML}}{\text{ML} + \text{MP}}$

Café du Donut

- The café buys donuts each day for $4 per carton of 2 dozen donuts.
- Any cartons not sold are thrown away at the end of the day.
- If a carton is sold, the total revenue is $6.
- The marginal profit per carton is.

$$MP = \text{Marginal profit} = \$6 - \$4 = \$2$$

- The marginal loss is $4 per carton since cartons can not be returned or salvaged.

Café du Donut's Probability Distribution

DAILY SALES (CARTONS OF DOUGHNUTS)	PROBABILITY (P) THAT DEMAND WILL BE AT THIS LEVEL
4	0.05
5	0.15
6	0.15
7	0.20
8	0.25
9	0.10
10	0.10
Total	1.00

Table 6.6

Café du Donut Example

Step 1. Determine the value of $\frac{\text{ML}}{\text{ML}+\text{MP}}$ for the decision rule.

$$P \geq \frac{\text{ML}}{\text{ML}+\text{MP}} = \frac{\$4}{\$4+\$2} = \frac{4}{6} = 0.67$$

$$P \geq 0.67$$

Step 2. Add a new column to the table to reflect the probability that doughnut sales will be at each level or greater.

Marginal Analysis for Café du Donut

DAILY SALES (CARTONS OF DOUGHNUTS)	PROBABILITY (P) THAT DEMAND WILL BE AT THIS LEVEL	PROBABILITY (P) THAT DEMAND WILL BE AT THIS LEVEL OR GREATER
4	0.05	1.00 ≥ 0.66
5	0.15	0.95 ≥ 0.66
6	0.15	0.80 ≥ 0.66
7	0.20	0.65
8	0.25	0.45
9	0.10	0.20
10	0.10	0.10
Total	1.00	

Table 6.7

Café du Donut Example

Step 3. Keep ordering additional cartons as long as the probability of selling at least one additional carton is greater than P, which is the indifference probability.

$$P \text{ at 6 cartons} = 0.80 > 0.67$$

Marginal Analysis with the Normal Distribution

- We first need to find four values:

  1. The average or mean sales for the product, μ
  2. The standard deviation of sales, σ
  3. The marginal profit for the product, MP.
  4. The marginal loss for the product, ML.

- We let X^* = optimal stocking level.

Steps of Marginal Analysis with the Normal Distribution

1. Determine the value of $\frac{\text{ML}}{\text{ML} + \text{MP}}$ for the problem.
2. Locate P on the normal distribution (Appendix A) and find the associated Z-value.
3. Find X^* using the relationship:

$$Z = \frac{X^* - \mu}{\sigma}$$

to solve for the resulting stocking policy:

$$X^* = \mu + Z\sigma$$

Joe's Stocking Decision for the Chicago Tribune

- **Demand for the *Chicago Tribune* at Joe's Newsstand averages 60 papers a day with a standard deviation of 10.**
- **The marginal loss is 20 cents and the marginal profit is 30 cents.**

Step 1. Joe should stock the *Tribune* as long as the probability of selling the last unit is at least ML/(ML + MP):

$$\frac{\text{ML}}{\text{ML}+\text{MP}} = \frac{20\text{ cents}}{20\text{ cents}+30\text{ cents}} = \frac{20}{50} = 0.40$$

Let P = 0.40.

Joe's Stocking Decision for the Chicago Tribune

Step 2. Using the normal distribution in Figure 6.10, we find the appropriate Z value

Z = 0.25 standard deviations from the mean

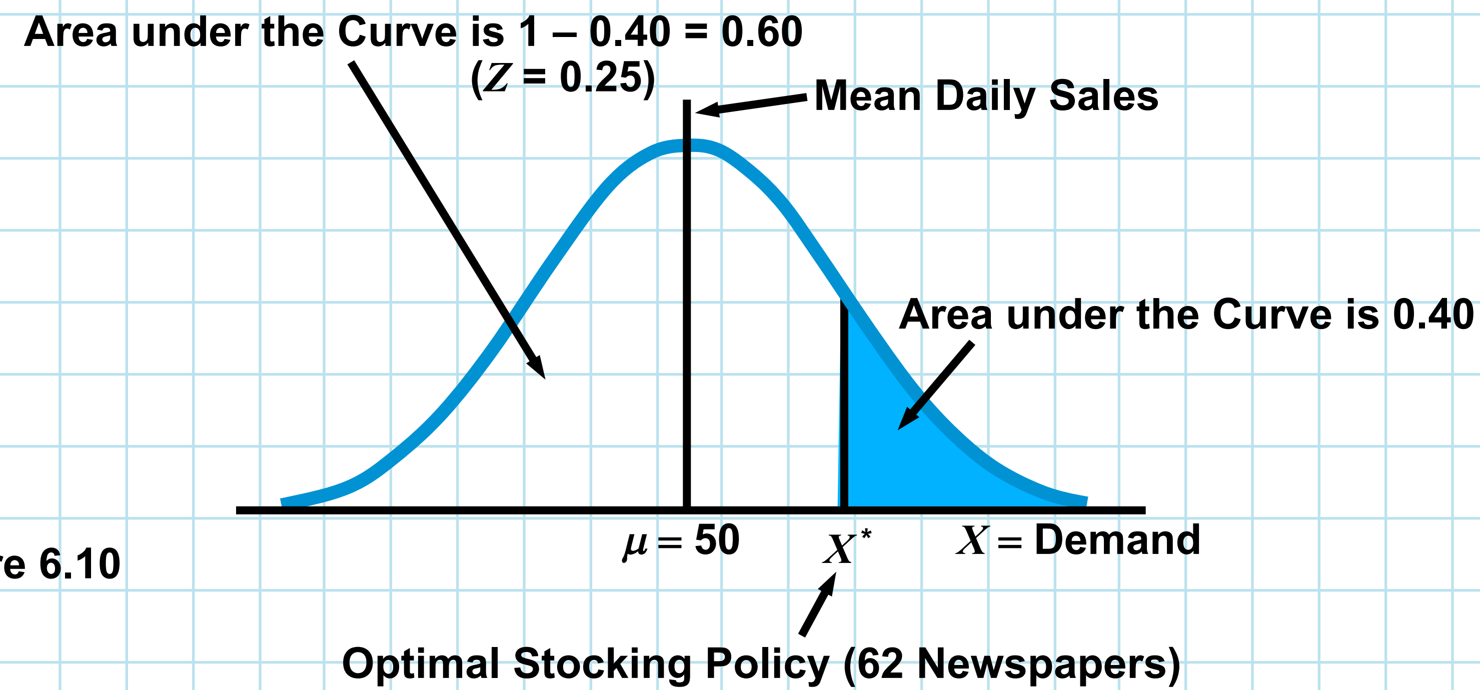


Figure 6.10

Joe's Stocking Decision for the Chicago Tribune

Step 3. In this problem, $\mu = 60$ and $\sigma = 10$, so

$$0.25 = \frac{X^* - 60}{10}$$

or

$$X^* = 60 + 0.25(10) = 62.5, \text{ or } 62 \text{ newspapers}$$

Joe should order 62 newspapers since the probability of selling 63 newspapers is slightly less than 0.40

Joe's Stocking Decision for the Chicago Tribune

- The procedure is the same when $P > 0.50$.
- Joe also stocks the *Chicago Sun-Times.*
- Marginal loss is 40 cents and marginal profit is 10 cents.
- Daily sales average 100 copies with a standard deviation of 10 papers.

$$\frac{\text{ML}}{\text{ML} + \text{MP}} = \frac{40 \text{ cents}}{40 \text{ cents} + 10 \text{ cents}} = \frac{40}{50} = 0.80$$

- From Appendix A:

Z = – 0.84 standard deviations from the mean

Joe's Stocking Decision for the Chicago Tribune

With $\mu = 100$ and $\sigma = 10$

$$-0.84 = \frac{X^* - 100}{10}$$

or

$$X^* = 100 - 0.84(10)$$
$$= 91.6\text{, or 91 newspapers}$$

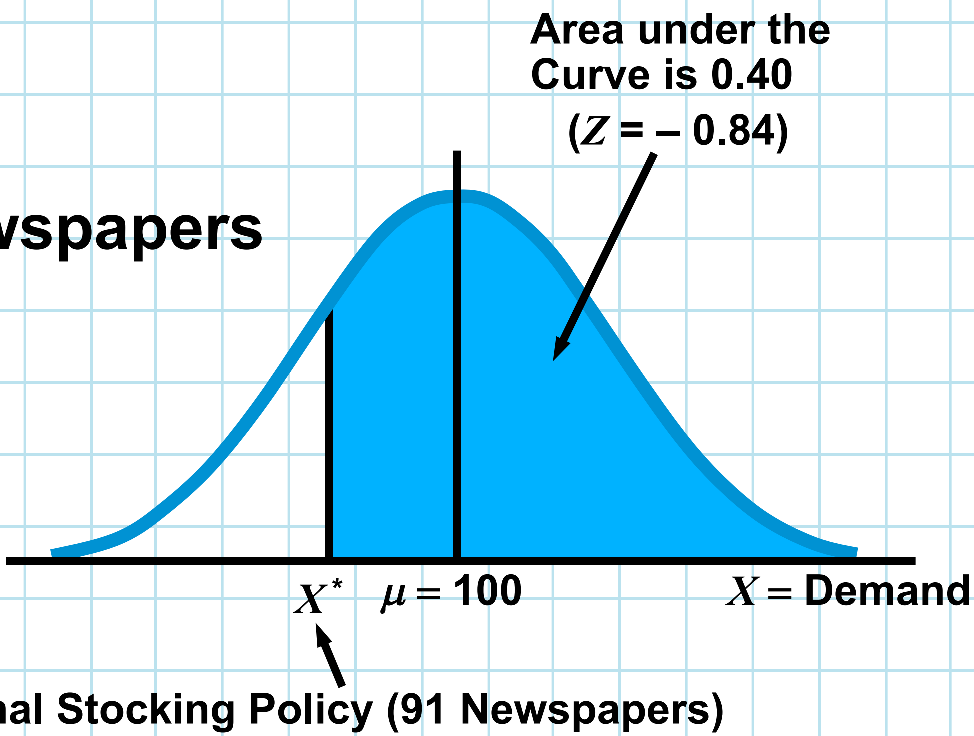


Figure 6.11

ABC Analysis

- The purpose of ABC analysis is to divide the inventory into three groups based on the overall inventory value of the items.
- Group A items account for the major portion of inventory costs.
  - Typically about 70% of the dollar value but only 10% of the quantity of items.
  - Forecasting and inventory management must be done carefully.
- Group B items are more moderately priced.
  - May represent 20% of the cost and 20% of the quantity.
- Group C items are very low cost but high volume.
  - It is not cost effective to spend a lot of time managing these items.

Summary of ABC Analysis

INVENTORY GROUP	DOLLAR USAGE (%)	INVENTORY ITEMS (%)	ARE QUANTITATIVE CONTROL TECHNIQUES USED?
A	70	10	Yes
B	20	20	In some cases
C	10	70	No

Table 6.8

Dependent Demand: The Case for Material Requirements Planning

- **All the inventory models discussed so far have assumed demand for one item is independent of the demand for any other item.**
- **However, in many situations items demand is dependent on demand for one or more other items.**
- **In these situations, *Material Requirements Planning (MRP)* can be employed effectively.**

Dependent Demand: The Case for Material Requirements Planning

- Some of the benefits of MRP are:
  1. Increased customer service levels.
  2. Reduced inventory costs.
  3. Better inventory planning and scheduling.
  4. Higher total sales.
  5. Faster response to market changes and shifts.
  6. Reduced inventory levels without reduced customer service.
- Most MRP systems are computerized, but the basic analysis is straightforward.

Material Structure Tree

- The first step is to develop a ***bill of materials*** (***BOM***).
- The BOM identifies components, descriptions, and the number required for production of one unit of the final product.
- From the BOM we can develop a material structure tree.
- We use the following data:
  - Demand for product A is 50 units.
  - Each A requires 2 units of B and 3 units of C.
  - Each B requires 2 units of D and 3 units of E.
  - Each C requires 1 unit of E and 2 units of F.

Material Structure Tree

Material structure tree for Item A

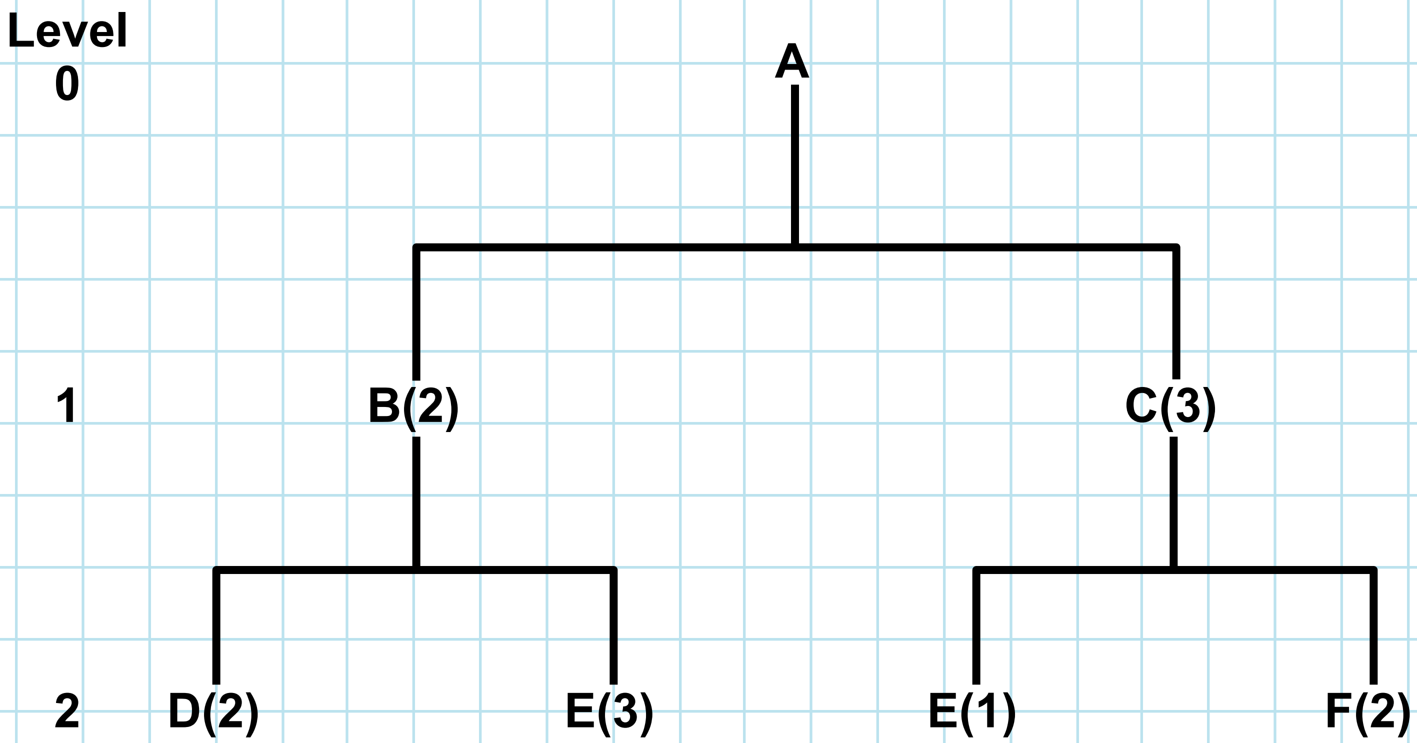


Figure 6.12

Material Structure Tree

- It is clear from the three that the demand for B, C, D, E, and F is completely dependent on the demand for A.
- The material structure tree has three levels: 0, 1, and 2.
- Items above a level are called ***parents.***
- Items below any level are called ***components.***
- The number in parenthesis beside each item shows how many are required to make the item above it.

Material Structure Tree

We can use the material structure tree and the demand for Item A to compute demands for the other items.

Part B: $2 \times$ number of A's $= 2 \times 50 = 100$.

Part C: $3 \times$ number of A's $= 3 \times 50 = 150$.

Part D: $2 \times$ number of B's $= 2 \times 100 = 200$.

Part E: $3 \times$ number of B's $+ 1 \times$ number of C's
$= 3 \times 100 + 1 \times 150 = 450$.

Part F: $2 \times$ number of C's $= 2 \times 150 = 300$.

Gross and Net Material Requirements Plan

- Once the materials structure tree is done, we construct a gross material requirements plan.
- This is a time schedule that shows:
  - when an item must be ordered when there is no inventory on hand, or
  - when the production of an item must be started in order to satisfy the demand for the finished product at a particular date.
- We need lead times for each of the items.

Item A – 1 week	Item D – 1 week
Item B – 2 weeks	Item E – 2 weeks
Item C – 1 week	Item F – 3 weeks

Gross Material Requirements Plan for 50 Units of A

Week

		1	2	3	4	5	6	
A	Required Date						50	Lead Time = 1 Week
	Order Release					50		
B	Required Date					100		Lead Time = 2 Weeks
	Order Release			100				
C	Required Date					150		Lead Time = 1 Week
	Order Release				150			
D	Required Date			200				Lead Time = 1 Week
	Order Release		200					
E	Required Date			300	150			Lead Time = 2 Weeks
	Order Release	300	150					
F	Required Date				300			Lead Time = 3 Weeks
	Order Release	300						

Figure 6.13

Net Material Requirements Plan

A net material requirements plan can be constructed from the gross materials requirements plan and the following on-hand inventory information:

ITEM	ON-HAND INVENTORY
A	10
B	15
C	20
D	10
E	10
F	5

Table 6.9

Net Material Requirements Plan

- Using this data we can construct a plan that includes:
  - Gross requirements.
  - On-hand inventory.
  - Net requirements.
  - Planned-order receipts.
  - Planned-order releases.
- The net requirements plan is constructed like the gross requirements plan.

Net Material Requirements Plan for 50 Units of A

Item			1	2	3	4	5	6	Lead Time
A	Gross							50	1
	On-Hand	10						10	
	Net							40	
	Order Receipt							40	
	Order Release						40		
B	Gross						80[A]		2
	On-Hand	15					15		
	Net						65		
	Order Receipt						65		
	Order Release				65				

Figure 6.14(a)

Net Material Requirements Plan for 50 Units of A

Item			Week 1	2	3	4	5	6	Lead Time
C	Gross						120^A		1
	On-Hand	20					10		
	Net						100		
	Order Receipt						100		
	Order Release					100			
D	Gross				130^B				1
	On-Hand	10			10				
	Net				120				
	Order Receipt				120				
	Order Release			120					

Figure 6.14(b)

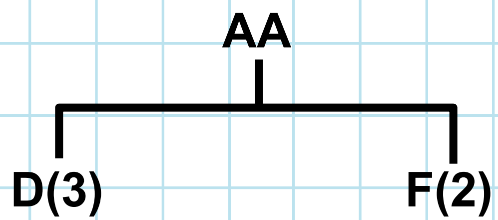
Net Material Requirements Plan for 50 Units of A

Item		Week 1	2	3	4	5	6	Lead Time
E	Gross			195[B]	100[C]			2
	On-Hand 10			10	0			
	Net			185	100			
	Order Receipt			185	100			
	Order Release	185	100					
F	Gross				200[C]			3
	On-Hand 5				5			
	Net				195			
	Order Receipt				195			
	Order Release	195						

Figure 6.14(c)

Two or More End Products

- Most manufacturing companies have more than one end item.
- In this example, the second product is AA and it has the following material structure tree:



- If we require 10 units of AA, the gross requirements for parts D and F can be computed:

Part D: $3 \times$ number of AA's $= 3 \times 10 = 30$
Part F: $2 \times$ number of AA's $= 2 \times 10 = 20$

Two or More End Products

- The lead time for AA is one week.
- The gross requirement for AA is 10 units in week 6 and there are no units on hand.
- This new product can be added to the MRP process.
- The addition of AA will only change the MRP schedules for the parts contained in AA.

- MRP can also schedule spare parts and components.
- These have to be included as gross requirements.

Net Material Requirements Plan, Including AA

Figure 6.15

Item	Inventory	Week						Lead Time
		1	2	3	4	5	6	
AA	Gross						10	1 Week
	On-Hand: 0						0	
	Net						10	
	Order Receipt						10	
	Order Release					10		
A	Gross						50	1 Week
	On-Hand: 10						10	
	Net						40	
	Order Receipt						40	
	Order Release					40		
B	Gross					80[A]		2 Weeks
	On-Hand: 15					15		
	Net					65		
	Order Receipt					65		
	Order Release			65				
C	Gross					120[A]		1 Week
	On-Hand: 20					20		
	Net					100		
	Order Receipt					100		
	Order Release				100			
D	Gross			130[B]		30[AA]		1 Week
	On-Hand: 10			10		0		
	Net			120		30		
	Order Receipt			120		30		
	Order Release		120		30			
E	Gross			195[B]	100[C]			2 Weeks
	On-Hand: 10			10	0			
	Net			185	100			
	Order Receipt			185	100			
	Order Release	185	100					
F	Gross				200[C]	20[AA]		3 Weeks
	On-Hand: 5				5	0		
	Net				195	20		
	Order Receipt				195	20		
	Order Release	195	20					

Just-in-Time (JIT) Inventory Control

- To achieve greater efficiency in the production process, organizations have tried to have less in-process inventory on hand.
- This is known as *JIT inventory.*
- The inventory arrives just in time to be used during the manufacturing process.
- One technique of implementing JIT is a manual procedure called *kanban.*

Just-in-Time Inventory Control

- Kanban in Japanese means "card."
- With a dual-card kanban system, there is a conveyance kanban, or C-kanban, and a production kanban, or P-kanban.
- Kanban systems are quite simple, but they require considerable discipline.
- As there is little inventory to cover variability, the schedule must be followed exactly.

4 Steps of Kanban

1. A user takes a container of parts or inventory along with its C-kanban to his or her work area.

   When there are no more parts or the container is empty, the user returns the container along with the C-kanban to the producer area.
2. At the producer area, there is a full container of parts along with a P-kanban.

   The user detaches the P-kanban from the full container and takes the container and the C-kanban back to his or her area for immediate use.

4 Steps of Kanban

3. The detached P-kanban goes back to the producer area along with the empty container

   The P-kanban is a signal that new parts are to be manufactured or that new parts are to be placed in the container and is attached to the container when it is filled .

4. This process repeats itself during the typical workday.

The Kanban System

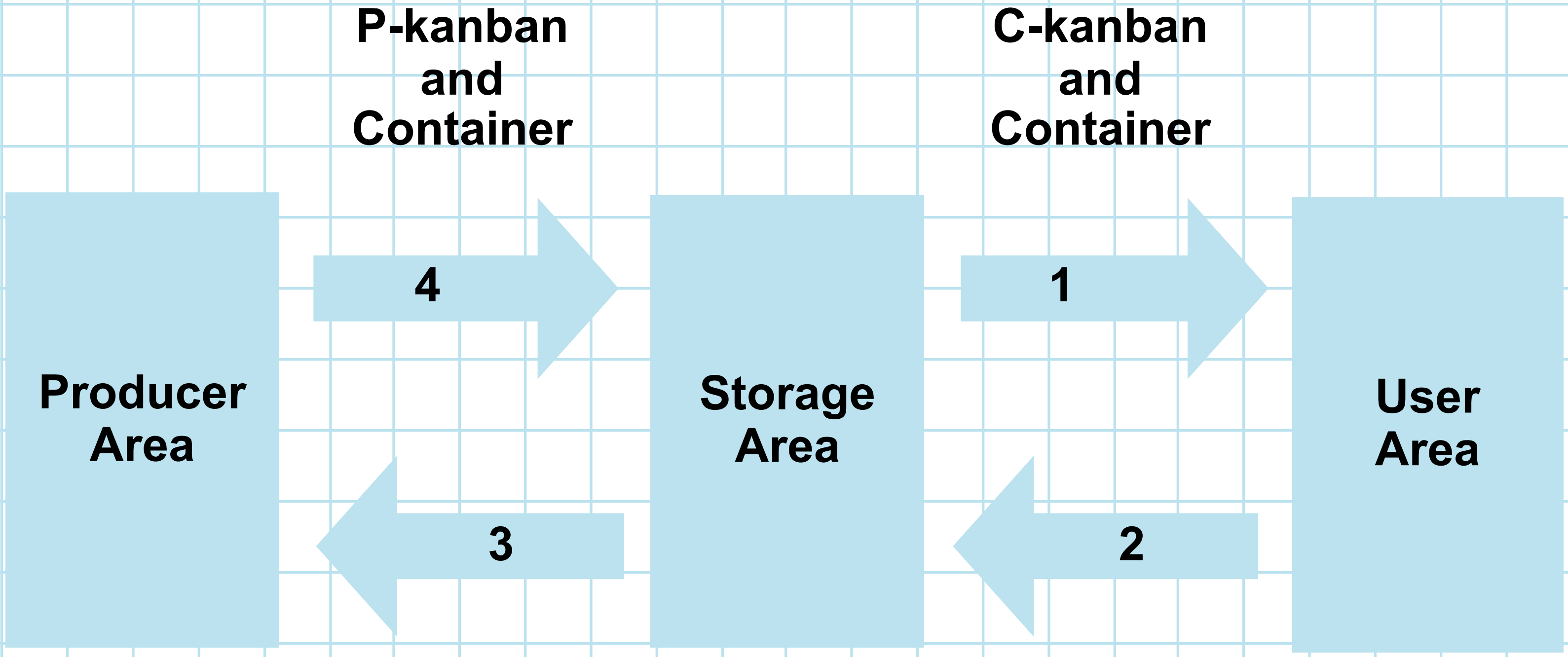


Figure 6.16

Enterprise Resource Planning

- **MRP has evolved to include not only the materials required in production, but also the labor hours, material cost, and other resources related to production.**
- **In this approach the term MRP II is often used and the word *resource* replaces the word *requirements.***
- **As this concept evolved and sophisticated software was developed, these systems became known as *enterprise resource planning* (*ERP*) systems.**

Enterprise Resource Planning

- The objective of an ERP System is to reduce costs by integrating all of the operations of a firm.
- Starts with the supplier of materials needed and flows through the organization to include invoicing the customer of the final product.
- Data are entered only once into a database where it can be quickly and easily accessed by anyone in the organization.
- Benefits include:
  - Reduced transaction costs.
  - Increased speed and accuracy of information.

Enterprise Resource Planning

- Drawbacks to ERP:
  - The software is expensive to buy and costly to customize.
    - Small systems can cost hundreds of thousands of dollars.
    - Large systems can cost hundreds of millions.
  - The implementation of an ERP system may require a company to change its normal operations.
  - Employees are often resistant to change.
  - Training employees on the use of the new software can be expensive.

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