Chapter 6 – Inventory Management

Fundamentals of Operations Management

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Learning Objectives

- Describe the different types and uses of inventory
- Describe the objectives of inventory management
- Calculate inventory performance measures
- Understand relevant costs associated with inventory
- Perform ABC inventory control & analysis
- Understand the role of cycle counting in inventory record accuracy

Learning Objectives – con't

- Understand inventory's role in service organizations
- Calculate order quantities
- Evaluate the total relevant costs of different inventory policies
- Understand why companies don't always use the optimal order quantity
- Understand how to justify smaller order sizes
- Calculate appropriate safety stock inventory policies
- Calculate order quantities for single-period inventory

Types of Inventory

Inventory comes in many shapes and sizes such as:

- **Raw materials** – purchased items or extracted materials transformed into components or products
- **Components** – parts or subassemblies used in final product
- **Work-in-process** – items in process throughout the plant
- **Finished goods** – products sold to customers
- **Distribution/pipeline inventory** – finished goods in the distribution system

Types of Inventory

How Companies Use Inventory – Functions of Inventory

1. Anticipation or seasonal inventory
2. Fluctuation Inventory or Safety stock: buffer demand fluctuations
3. Lot-size or cycle stock: take advantage of quantity discounts or purchasing efficiencies
4. Transportation or Pipeline (goods-in-transit) inventory
5. Speculative or hedge inventory protects against some future event, e.g. labor strike, rise in prices
6. Maintenance, repair, and operating (MRO) inventories

Objectives of Inventory Management

Provide desired customer service level

- Customer service is the ability to satisfy customer requirements
  - Percentage of orders shipped on schedule
  - Percentage of line items shipped on schedule
  - Percentage of $ volume shipped on schedule
  - Idle time due to material and component shortages

Inventory Objectives con't

Provide for cost-efficient operations:

- Buffer stock for smooth production flow
- Maintain a level work force
- Allowing longer production runs & quantity discounts

- **Minimum inventory investments:**
  - Inventory turnover
  - Weeks, days, or hours of supply

Customer Service Level Examples

- **Percentage of Orders Shipped on Schedule**
  - Good measure if orders have similar value. Does not capture value.
  - If one company represents 50% of your business but only 5% of your orders, 95% on schedule could represent only 50% of value
- **Percentage of Line Items Shipped on Schedule**
  - Recognizes that not all orders are equal, but does not capture $ value of orders. More expensive to measure. Ok for finished goods.
  - A 90% service level might mean shipping 225 items out of the total 250 line items totaled from 20 orders scheduled
- **Percentage Of Dollar Volume Shipped on Schedule**
  - Recognizes the differences in orders in terms of both line items and $ value

Inventory Investment Measures Example: The Coach Motor Home Company has annual cost of goods sold of $10,000,000. The average inventory value at any point in time is $384,615. Calculate inventory turnover and weeks/days of supply.

- **Inventory Turnover:**

$$\textbf{Turnover} = \frac{\textbf{annual cost of goods sold}}{\textbf{average inventory value}} = \frac{\textbf{\$10,000,000}}{\textbf{\$384,615}} = \textbf{26 inventory turns}$$

- **Weeks/Days of Supply:**

$$\text{Weeks of Supply} = \frac{\text{average inventory on hand in dollars}}{\text{average weekly usage in dollars}} = \frac{\$384,615}{\$10,000,000/52} = 2\text{weeks}$$

$$\textbf{Days of Supply} = \frac{\textbf{\$384,615}}{\textbf{\$10,000,000/260}} = \textbf{10 days}$$

Relevant Inventory Costs

Purchase Cost	Includes price paid for the item plus other direct costs associated with the purchase
Holding Costs	Include the variable expenses incurred by the plant related to the volume of inventory held (15-25%). E.g., interest, insurance, depreciation, obsolescence, deterioration, spoilage, warehouse cost (rent, security, light), etc
Capital Costs	The higher of the cost of capital or the opportunity cost for the company

Relevant Inventory Costs

Ordering Cost	Fixed, constant dollar amount incurred for each order placed (e.g: postage, telephone, fax, email, setup cost, etc.)
Shortage Costs/ Stock out cost	Loss of customer goodwill, back order handling, and lost sales.
Risk costs	Obsolescence, damage, deterioration, theft, insurance and taxes
Storage costs	Included the variable expenses for space, workers, and equipment related to the volume of inventory held

Determining Order Quantities

Lot-for-lot	Order exactly what is needed
Fixed-order quantity	Specifies the number of units to order whenever an order is placed
Min-max system	Places a replenishment order when the on-hand inventory falls below the predetermined minimum level.
Order *n periods*	Order quantity is determined by total demand for the item for the next ***n*** periods

ABC Inventory Classification

ABC classification is a method for determining level of control and frequency of review of inventory items

- A Pareto analysis can be done to segment items into value categories depending on annual dollar volume
- **A Items** – typically 20% of the items accounting for 80% of the inventory value-use Q system
- **B Items** – typically an additional 30% of the items accounting for 15% of the inventory value-use Q or P
- **C Items** – Typically the remaining 50% of the items accounting for only 5% of the inventory value-use P

The AAU Corp. is considering doing an ABC analysis on its entire inventory but has decided to test the technique on a small sample of 15 of its SKU's. The annual usage and unit cost of each item is shown below

ABC Problem Data

Item	Unit $ Value	Annual Usage (in units)
101	12.00	80
102	50.00	10
103	15.00	50
104	50.00	40
105	40.00	80
106	75.00	220
107	4.00	250
108	1.50	400
109	2.00	250
110	25.00	500
111	5.00	450
112	7.50	80
113	3.50	250
114	1.00	1200
115	15.00	300

(A) First calculate the annual dollar volume for each item

- **Solution**

(a)

ABC Annual Usage Values

Item	Unit $ Value	Annual Usage (in units)	Annual Usage ($)
101	12.00	80	960
102	50.00	10	500
103	15.00	50	750
104	50.00	40	2000
105	40.00	80	3200
106	75.00	220	16,500
107	4.00	250	1000
108	1.50	400	600
109	2.00	250	500
110	25.00	500	12,500
111	5.00	450	2250
112	7.50	80	600
113	3.50	250	875
114	1.00	1200	1200
115	15.00	300	4500
		Total	$47,935

B) List the items in descending order based on annual dollar volume. (C) Calculate the cumulative annual dollar volume as a percentage of total dollars. (D) Classify the items into groups

(b, c, and d)

ABC Solution

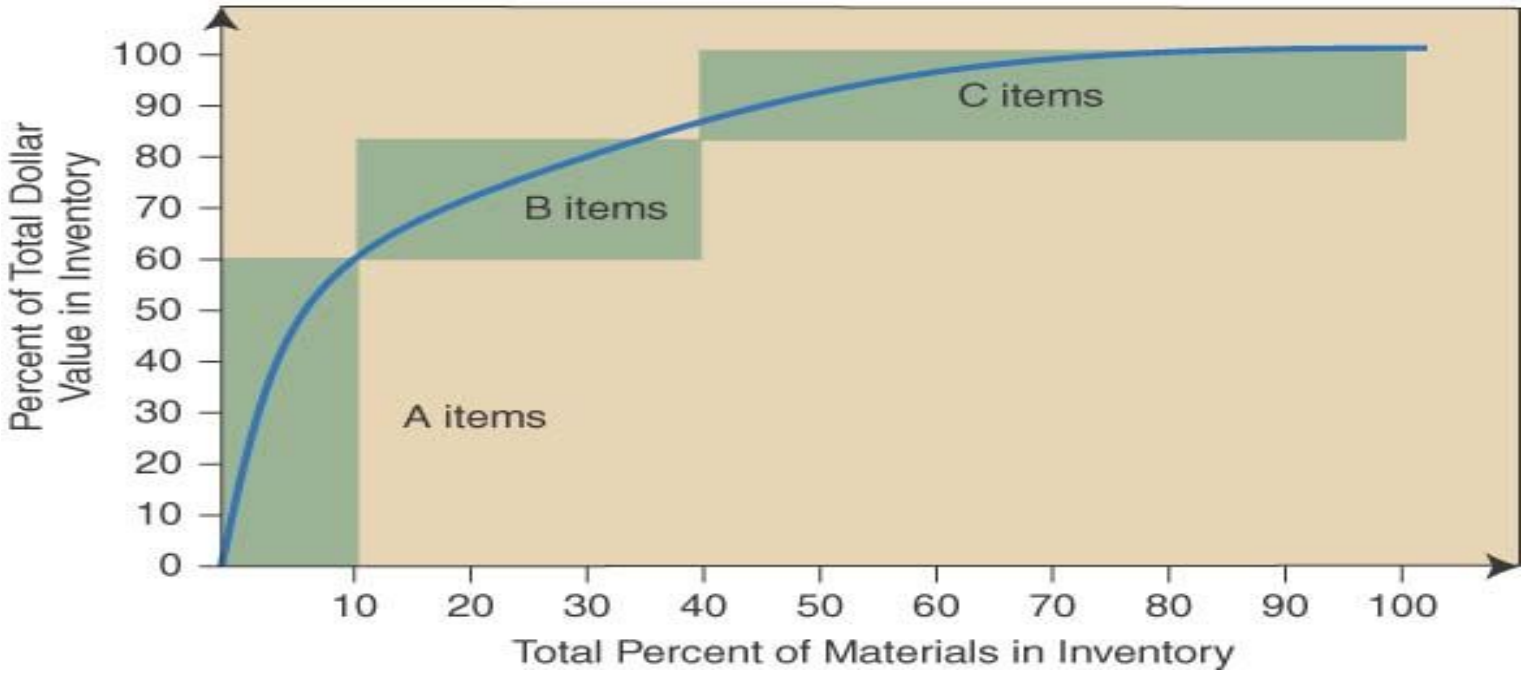
Item	Annual Usage ($)	Percentage of Total Dollars	Cumulative Percentage of Total Dollars	Item Classification
106	16,500	34.4	34.4	A
110	12,500	26.1	60.5	A
115	4500	9.4	69.9	B
105	3200	6.7	76.6	B
111	2250	4.7	81.3	B
104	2000	4.2	85.5	B
114	1200	2.5	88.0	C
107	1000	2.1	90.1	C
101	960	2.0	92.1	C
113	875	1.8	93.9	C
103	750	1.6	95.5	C
108	600	1.3	96.8	C
112	600	1.3	98.1	C
102	500	1.0	99.1	C
109	500	1.0	100.1*	C
Total	**$47,935**			

*Total exceeds 100% due to rounding.

Remember that these are not absolute rules for classifying items. Your company wants to group their more valuable items together to make sure that they get the most control.

Graphical solution for AAU Corp showing the ABC classification of materials

- **The A items (106 and 110) account for 60.5% of the value and 13.3% of the items**
- **The B items (115,105,111,and 104) account for 25% of the value and 26.7% of the items**
- **The C items make up the last 14.5% of the value and 60% of the items**
- **How might you control each item classification? Different ordering rules for each?**



Inventory Record Accuracy

- **Inaccurate inventory records can cause:**
  - Lost sales
  - Disrupted operations
  - Poor customer service
  - Lower productivity
  - Planning errors and expediting

Inventory Record Accuracy

Two methods for checking record accuracy:

- Periodic counting - physical inventory is taken periodically, usually annually
- Cycle counting - daily counting of prespecified items provides the following advantages:
  - Timely detection and correction of inaccurate records
  - Elimination of lost production time due to unexpected stock outs
  - Structured approach using employees trained in cycle counting

Inventory in Service Organizations

- Achieving good inventory control may require the following:
  - Select, train and discipline personnel
  - Maintain tight control over incoming shipments
  - Maintain tight control over outgoing shipments

Determining Order Quantities

Inventory management and control are managed with SKU (stock control units)

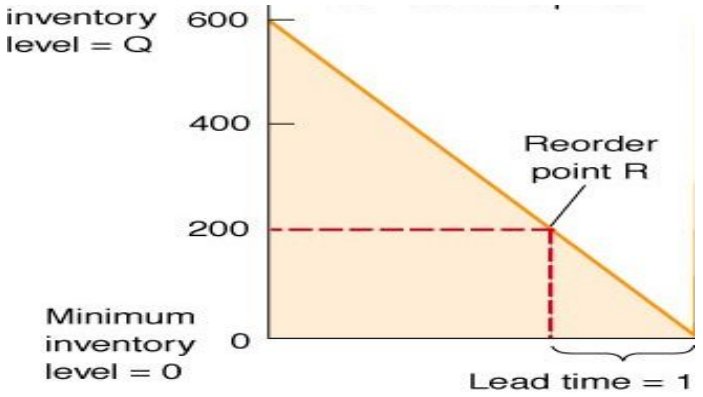
Lot-for-lot	Order exactly what is needed.
Fixed-order quantity	Order a predetermined amount each time an order is placed.
Min-max system	When on-hand inventory falls below a predetermined minimum level, order a quantity that will take the inventory back up to its predetermined maximum level.
Order *n* periods	Order enough to satisfy demand for the next *n* periods.

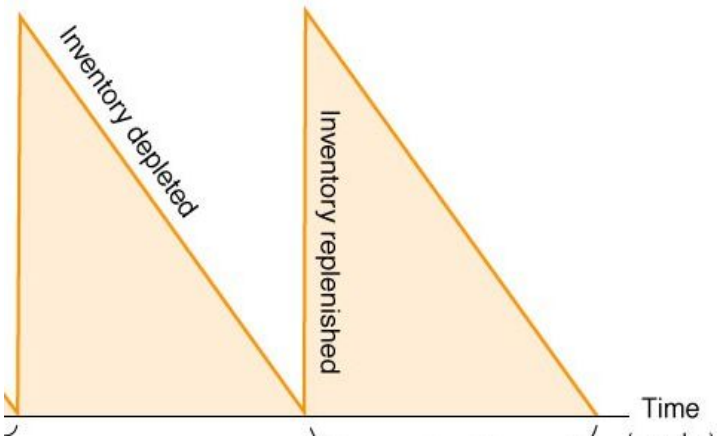
Mathematical Models for Determining Order Quantity

- **Economic Order Quantity (EOQ)**
  - An optimizing method used for determining order quantity and reorder points
  - Part of **continuous review system** which tracks on-hand inventory each time a withdrawal is made
- **Economic Production Quantity (EPQ)**
  - A model that allows for incremental product delivery
- **Quantity Discount Model**
  - Modifies the EOQ process to consider cases where quantity discounts are available

EOQ Assumptions

- Demand is known & constant - no safety stock is required
- Lead time is known & constant
- No quantity discounts are available
- Ordering (or setup) costs are constant
- All demand is satisfied (no shortages)
- The order quantity arrives in a single shipment

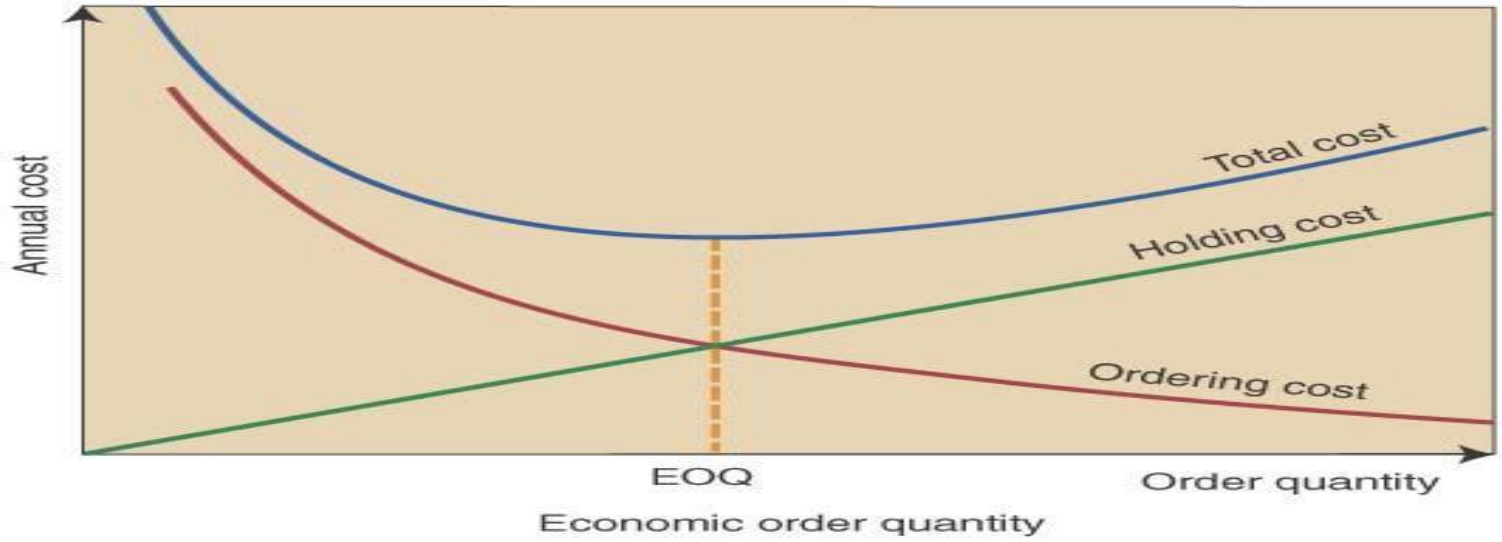




Total Annual Inventory Cost with EOQ Model

Total annual cost= annual ordering cost + annual holding costs

$$TC_Q = \left(\frac{D}{Q}\right)S + \left(\frac{Q}{2}\right)H; \quad \text{and} \quad Q = \sqrt{\frac{2DS}{H}}$$



Continuous (Q) Review System Example: A computer company has annual demand of 10,000. They want to determine EOQ for circuit boards which have an annual holding cost (H) of $6/unit, and an ordering cost (S) of $75. They want to calculate TC and the reorder point (R) if the purchasing lead time is 5 days.

- **EOQ (Q)**

$$Q = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2 * 10{,}000 * \$75}{\$6}} = 500 \text{ units}$$

- **Reorder Point (R)**

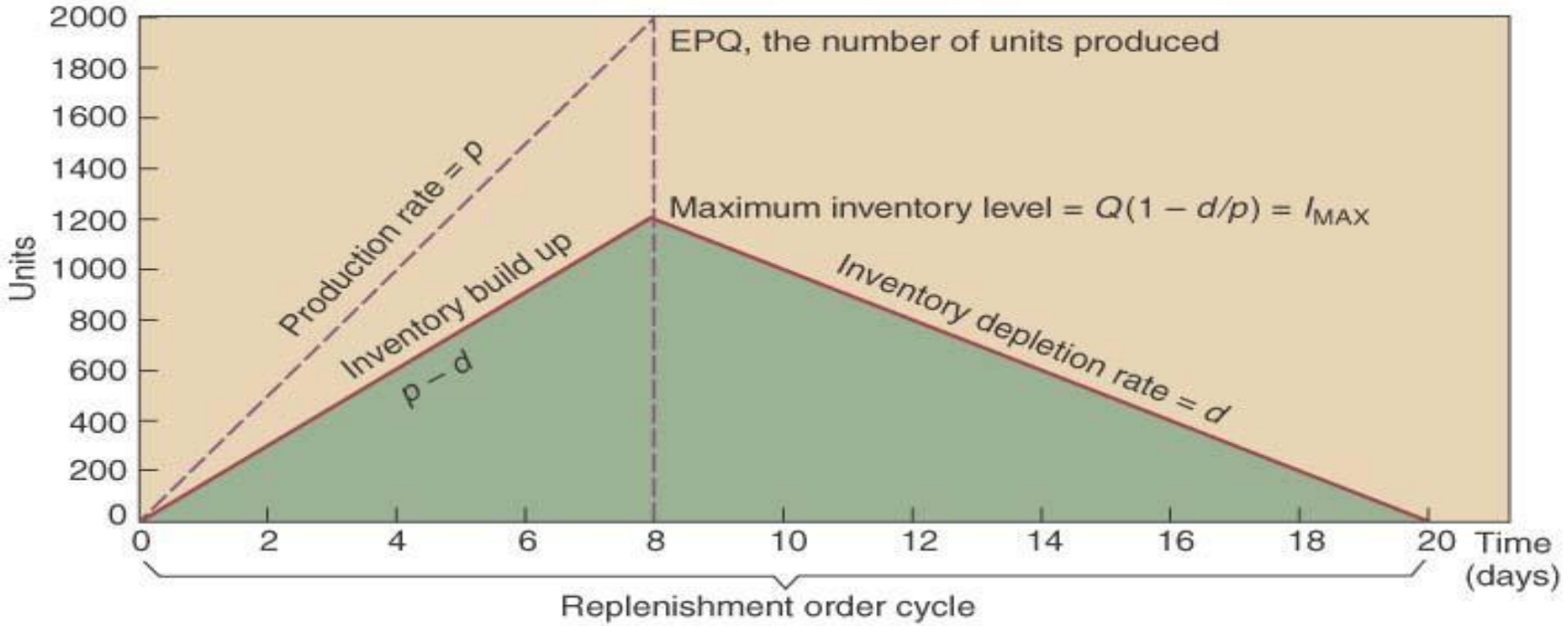
$$R = \text{Daily Demand x Lead Time} = \frac{10{,}000}{250 \text{ days}} * 5 \text{ days} = 200 \text{ units}$$

- **Total Inventory Cost (TC)**

$$TC = \left(\frac{10{,}000}{500}\right)\$75 + \left(\frac{500}{2}\right)\$6 = \$1500 + \$1500 = \$3000$$

Economic Production Quantity (EPQ)

Same assumptions as the EOQ except: inventory arrives in increments & draws down as it arrives



Order quantity 2000 units
Daily demand (d) = 100 units
Daily production (p) = 250 units

Calculating EPQ

- **Total cost:**

$$TC_{EPQ} = \left(\frac{D}{Q}S\right) + \left(\frac{I_{MAX}}{2}H\right)$$

- **Maximum inventory:**
  - d=avg. daily demand rate
  - p=daily production rate

$$I_{MAX} = Q\left(1 - \frac{d}{p}\right)$$

- **Calculating EPQ**

$$EPQ = \sqrt{\frac{2DS}{H\left(1 - \frac{d}{p}\right)}}$$

EPQ Problem: **HP Ltd. Produces premium plant food in 50# bags. Demand is 100,000 lbs/week. They operate 50 wks/year; HP produces 250,000 lbs/week. Setup cost is $200 and the annual holding cost rate is $.55/bag. Calculate the EPQ. Determine the maximum inventory level. Calculate the total cost of using the EPQ policy.**

$$EPQ = \sqrt{\frac{2DS}{H\left(1-\frac{d}{p}\right)}}$$

$$I_{MAX} = Q\left(1-\frac{d}{p}\right)$$

$$TC_{EPQ} = \left(\frac{D}{Q}S\right) + \left(\frac{I_{MAX}}{2}H\right)$$

EPQ Problem Solution

$$\mathbf{EPQ} = \sqrt{\frac{\mathbf{2DS}}{\mathbf{H}\left(\mathbf{1}-\frac{\mathbf{d}}{\mathbf{p}}\right)}}$$

$$EPQ = \sqrt{\frac{2(50)(100{,}000)(200)}{.55\left(1-\frac{100{,}000}{250000}\right)}} = 77{,}850\,Bags$$

$$\mathbf{I_{MAX}} = \mathbf{Q}\left(\mathbf{1}-\frac{\mathbf{d}}{\mathbf{p}}\right)$$

$$I_{MAX} = 77{,}850\left(1-\frac{100{,}000}{250{,}000}\right) = 46{,}710\,bags$$

$$\mathbf{TC_{EPQ}} = \left(\frac{\mathbf{D}}{\mathbf{Q}}\mathbf{S}\right)+\left(\frac{\mathbf{I_{MAX}}}{\mathbf{2}}\mathbf{H}\right)$$

$$TC = \left(\frac{5{,}000{,}000}{77{,}850}\right)(200)+\left(\frac{46{,}710}{2}\right)(.55) = \$25{,}690$$

Quantity Discount Model

- **Same as the EOQ model, except:**
  - Unit price depends upon the quantity ordered

- **The total cost equation becomes:**

$$TC_{QD} = \left(\frac{D}{Q}S\right) + \left(\frac{Q}{2}H\right) + CD$$

Quantity Discount Procedure

- Calculate the EOQ at the lowest price
- Determine whether the EOQ is feasible at that price
  - Will the vendor sell that quantity at that price?
- If yes, stop – if no, continue
- Check the feasibility of EOQ at the next higher price

QD Procedure con't

- Continue until you identify a feasible EOQ
- Calculate the total costs (including total item cost) for the feasible EOQ model
- Calculate the total costs of buying at the minimum quantity required for each of the cheaper unit prices
- **Compare the total cost of each option & choose the lowest cost alternative**
- **Any other issues to consider?**

Quantity Discount Example: Collin's Sport store is considering going to a different hat supplier. The present supplier charges $10/hat and requires minimum quantities of 490 hats. The annual demand is 12,000 hats, the ordering cost is $20, and the inventory carrying cost is 20% of the hat cost, a new supplier is offering hats at $9 in lots of 4000. Who should he buy from?

- **EOQ at lowest price $9. Is it feasible?**

$$EOQ_{\$9} = \sqrt{\frac{2(12{,}000)(20)}{\$1.80}} = 516 \text{ hats}$$

- **Since the EOQ of 516 is not feasible, calculate the total cost (C) for each price to make the decision**

$$C_{\$10} = \frac{12{,}000}{490}(\$20) + \frac{490}{2}(\$2) + \$10(12{,}000) = \$120{,}980$$

$$C_{\$9} = \frac{12{,}000}{4000}(\$20) + \frac{4000}{2}(\$1.80) + \$9(12{,}000) = \$101{,}660$$

- **4000 hats at $9 each saves $19,320 annually. Space?**

Why Companies Don't *Always* Use Optimal Order Quantity

It is not unusual for companies to order less or more than the EOQ for several reasons:

- They may not have a known uniform demand;
- Some suppliers have minimum order quantity that are beyond the demand.

Justifying Smaller Order Quantities

JIT or "Lean Systems" would recommend reducing order quantities to the lowest practical levels

- Benefits from reducing **Q's**:
  - Improved customer responsiveness (inventory = Lead time)
  - Reduced Cycle Inventory
  - Reduced raw materials and purchased components
- Justifying smaller **EOQ's**:

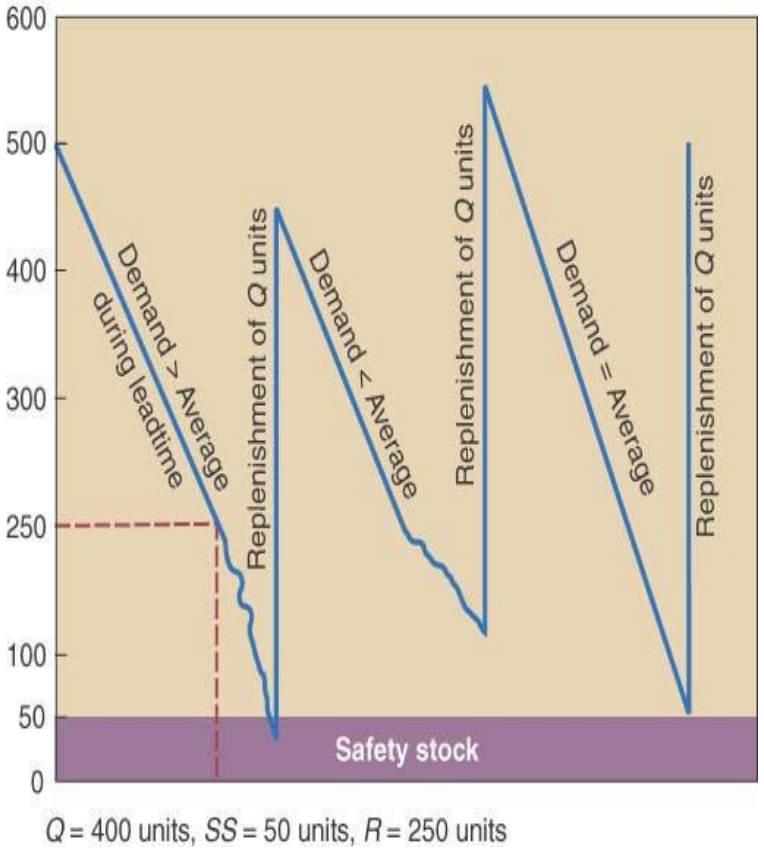
$$Q = \sqrt{\frac{2DS}{H}}$$

- Reduce **Q's** by reducing setup time **(S)**. **"Setup reduction" is a well documented, structured approach to reducing S**

Determining Safety Stock and Service Levels

- If demand or lead time is uncertain, safety stock can be added to improve order-cycle service levels
  - **R = dL +SS**
  - **Where SS =ZσdL, and Z is the number of standard deviations and σdL is standard deviation of the demand during lead time**

- **Order-cycle service level**
  - The probability that demand during lead time will not exceed on-hand inventory
  - A 95% service level (stockout risk of 5%) has a Z=1.645



Q = 400 units, SS = 50 units, R = 250 units

Periodic Review Systems

- Orders are placed at specified, fixed-time intervals (e.g. every Friday), for a order size **(Q)** to bring on-hand inventory **(OH)** up to the target inventory **(TI),** similar to the min-max system.
- **Advantages are:**
  - No need for a system to continuously monitor item
  - Items ordered from the same supplier can be reviewed on the same day saving purchase order costs
- **Disadvantages:**
  - Replenishment quantities (Q) vary
  - Order quantities may not quality for quantity discounts
  - On the average, inventory levels will be higher than Q systems-more stockroom space needed

Periodic Review Systems: Calculations for TI

- **Targeted Inventory level:**

  $TI = d(RP + L) + SS$

  d = average period demand

  RP = review period (days, wks)

  L = lead time (days, wks)

  $SS = z\sigma_{RP+L}$

- **Replenishment Quantity (Q)=TI-OH**

P System: an auto parts store calculated the EOQ for Drive Belts at 236 units and wants to compare the **Total Inventory Costs** for a **Q** vs. a **P Review System**. Annual demand (D) is 2704, avg. weekly demand is 52, weekly σ is 1.77 belts, and lead time is 3 weeks. The annual **TC** for the Q system is $229; H=$97, S=$10.

- **Review Period** $RP = \frac{Q}{D} \text{ x } 52\text{weeks} = \frac{236}{2704} \text{x} 52 = 5\text{wks}$
- **Target Inventory for 95% Service Level**

$$TI = d(RP + L) + SS = d(RP + L) + z\sigma_{RP+L}$$

$$TI = 52\text{ units}(5+3) + (1.645)\left(1.77\sqrt{5+3}\right) = 416 + 8 = 424\text{ belts}$$

- **Average On-Hand**

OH_{avg} = TI-dL=424-(52belts)(3wks) = 268 belts

- **Annual Total Cost (P System)**

$$TCp = \frac{52}{5}(\$10) + \frac{268}{2}(\$0.97) = 115 + 130 = \$245$$

$$\text{Annual Cost Difference} = \$245 - \$229 = +\$16$$

Single Period Inventory Model

The SPI model is designed for products that share the following characteristics:

- Sold at their regular price only during a single-time period
- Demand is highly variable but follows a known probability distribution
- Salvage value is less than its original cost so money is lost when these products are sold for their salvage value

- **Objective is to balance the gross profit of the sale of a unit with the cost incurred when a unit is sold after its primary selling period**

SPI Model Example: T-shirts are purchase in multiples of 10 for a charity event for $8 each. When sold during the event the selling price is $20. After the event their salvage value is just $2. From past events the organizers know the probability of selling different quantities of t-shirts within a range from 80 to 120

Payoff Table

Prob. Of Occurrence		**.20**	**.25**	**.30**	**.15**	**.10**	
Customer Demand		**80**	**90**	**100**	**110**	**120**	
# of Shirts Ordered					**Profit**		
80	$960	$960	$960	$960	$960	$960	
90	$900	$1080	$1080	$1080	$1080	$1040	
Buy 100		$840	$1020	$1200	$1200	$1200	$1083
110	$780	$ 960	$1140	$1320	$1320	$1068	
120	$720	$ 900	$1080	$1260	$1440	$1026	

Sample calculations:

Payoff (Buy 110)= sell 100($20-$8) –((110-100) x ($8-$2))= $1140

Expected Profit (Buy 100)= ($840 x .20)+($1020 x .25)+($1200 x .30) + ($1200 x .15)+($1200 x .10) = $1083

Inventory management within OM: How it all fits together

- Inventory management provides the materials and supplies needed to support actual manufacturing or service operations. Inventory replenishment policies guide the master production scheduler when determining which jobs and what quantity should be scheduled (Supplement D).
- Inventory management policies also affect the layout of the facility. A policy of small lot sizes and frequent shipments reduces the space needed to store materials (Ch 7).
- Longer throughput times reduce an organization's ability to respond quickly to changing customer demands (Ch 4).
- Good inventory management assures continuous supply and minimizes inventory investment while achieving customer service objectives.

Inventory Management Across the Organization

Inventory management policies affect functional areas throughout

- Accounting is concerned of the cost implications of inventory
- Marketing is concerned as stocking decision affect the level of customer service
- Information Systems tracks and controls inventory records

Chapter 12 Highlights

- Raw materials, purchased components, work-in-process, finished goods, distribution inventory and maintenance, repair and operating supplies are all types of inventory.
- The objectives of inventory management are to provide the desired level of customer service, to allow cost-efficient operations, and to minimize inventory investment.

Chapter 12 Highlights con't

- Inventory investment is measured in inventory turnover and/or level of supply. Inventory performance is calculated as inventory turnover or weeks, days, or hours of supply.
- Relevant inventory costs include item costs, holding costs, and shortage costs.

Chapter 12 Highlights con't

- Retailers, wholesalers, & food service organizations use tangible inventory even though they are service organizations.
- The ABC classification system allows a company to assign the appropriate level of control & frequency of review of an item based on its annual $ volume.
- Cycle counting is a method for maintaining accurate inventory records. Determining what and when to count are the major decisions.

Chapter 12 Highlights con't

- Lot-for-lot, fixed-order quantity, min-max systems, order n periods, periodic review systems, EOQ models, quantity discount models, and single-period models can be used to determine order quantities.
- Ordering decisions can be improved by analyzing total costs of an inventory policy. Total costs include ordering cost, holding cost, and material cost.

Chapter 12 Highlights con't

- Practical considerations can cause a company to not use the optimal order quantity, that is, minimum order requirements.
- Smaller lot sizes give a company flexibility and shorter response times. The key to reducing order quantities is to reduce ordering or setup costs.

Chapter 12 Highlights con't

- Calculating the appropriate safety stock policy enables companies to satisfy their customer service objective at minimum costs. The desired customer service level determines the appropriate z value.
- Inventory decisions about perishable products can be made using the single-period inventory model. The expected payoff is calculated to assist the quantity decision.

Chapter 12 Homework Hints

- Problem12.3: calculate inventory turnover, weekly, and daily supply
- Problem 12.12: calculate EOQ. TC is based on ordering + holding costs. Calculate reorder point.
- Problem 12.13: use data from problem 12.12. Quantity discount model. Use steps from slides or book. Choose best Q based on lowest TC.
- Problem 12.14: use data from problem 12.2. Determine Q based on period needs, then compare using TC for each option.
- Problem 12.20: ***ordering and holding costs are not needed for this problem***. Follow example 12.15 (p. 449) which uses four steps to do an ABC analysis.