



Inventory Management

Learning Objectives

After completing this chapter, you should be able to:

- List the purposes that inventory serves.
- Describe the different types of inventory.
- Explain the differences between perpetual and periodic inventory systems.
- Use the EOQ model to calculate order size.
- Calculate economic order quantities with quantity discounts.
- Determine the order point.
- Calculate safety stock.

10.1 Inventory

Inventory represents a significant investment of working capital for manufacturing companies such as Sony, wholesale and retail organizations such as Walmart, and food service providers such as Red Lobster. Firms like these should carefully consider the costs and benefits of holding inventory. When firms hold large amounts of inventory, they increase the costs associated with holding inventory including working capital, storage, and inventory management. Conversely, when firms hold small amounts of inventory, they must make frequent orders and accept the risk of being unable to satisfy customer demand. Making small and frequent orders tends to increase transaction, transportation, and equipment set-up costs. This is a fundamental trade-off in managing inventory.



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For manufacturing companies, wholesale and retail organizations, and food service providers, inventory represents a significant investment in working capital and a substantial cost to store and manage.

Multiple elements that impact this trade-off are discussed throughout the chapter and are relevant in the following chapters. This chapter also discusses methods for controlling independent demand inventory. The previous chapter addressed dependent demand items. Different systems for controlling and monitoring independent demand inventory are discussed and several mathematical models are described in this chapter. These systems help companies determine how much inventory should be ordered to minimize costs and also when to order inventory so that the desired level of customer service can be provided. Determining how much inventory to order and when is key to managing inventory.

Purpose of Inventory

Inventory can help businesses meet demand and work more efficiently. For many items, it does not make sense to produce them only when there is demand. When a customer walks into a retail store to buy groceries or cosmetics, they expect to walk out of the store with the item. When customers walk into a dealer's showroom to buy a car, they do not want to wait until the car is produced; they want to drive it away. There are also advantages to maintaining a stable level of production. Employment levels must be changed and equipment must be activated or shut down to allow production rates to fluctuate. These changes incur cost. In some cases, there simply is not enough capacity to meet the high level of demand, therefore, an alternative must be found. During low-demand times, firms can produce more product than they can currently sell with the unused portion going to inventory. The inventory can be used when demand accelerates and increasing the production level is not possible or is not economically feasible.

Many firms keep a cushion or "safety stock" of inventory to protect against unexpected demand. In this way, they can continue to meet customer demand without delays. Keeping

a safety stock of inventory is also useful when shipments from suppliers are delayed. This allows the firm to meet customer demand even though the supplier cannot meet its lead time commitment.

When producing goods, it is often important to separate steps in the production process that operate at different speeds. For example, a manufacturing part may be machined at one rate—one part in five minutes. The next step is to heat treat the machined parts in a furnace that operates in a batch mode—the furnace can hold up to 100 parts and take eight hours for heat treating. Therefore, an inventory of up to 100 parts should be accumulated before heat treatment.

In many situations, discounts are available to purchase a certain quantity. These can be quantity discounts or transportation discounts. A firm may need a certain amount of parts, but it may decide to buy more because a supplier is offering a discount for purchasing the larger amount. This is similar to buying a larger box of laundry detergent because it cost less per unit than the smaller box. Shipping in a certain amount may substantially reduce transportation costs. The best known transportation discount involves shipping in full truck load quantities rather than less than truck load amounts. The same can be said for shipping a full rail car versus less than a full rail car.

A company may try to hedge against possible price increases. When an increase in the purchase price is anticipated by the company or announced by the supplier, the company may order additional materials prior to the increase. This is similar to the quantity discount. Other times, firms may want to hedge against uncertainty in supply. A supplier may announce down time for its operations, or a supplier may have an upcoming contract negotiation with its labor union. Maintaining some extra inventory on hand may be prudent.

Types of Inventory

Several common types of inventory are:

1. Raw materials: These parts and materials are obtained from suppliers and are used in the production process.
2. Work-in-process (WIP): These are partly finished parts, components, subassemblies, or modules.
3. Finished goods: Items are ready to ship to the customer. No more work is required.
4. Replacement parts: These are maintained to replace other parts in machinery or equipment as those parts wear out.
5. Supplies: Parts or materials are used to support the production process, but not usually a component of the product. These items, such as lubricant and cutting tools, are consumed in the production process.
6. Transportation (pipeline): The portion of inventory that is in the process of being shipped through the distribution system.

10.2 Information Systems for Inventory Management

The purpose of inventory management systems is to provide information so that sufficient inventory will exist to meet the company's objectives. Of course, too much inventory can mean extra costs. Thus, the inventory management system is designed to ensure that inventory levels are maintained within a desired range for each item.

Today's computer systems and the widespread use of bar codes (as shown in Figure 10.1), have made inventory control more automated. It is not always possible, or even desirable, to computerize all inventory control. This section describes different systems and how they can be used, either with or without computers. All these systems focus on helping companies determine what, when, and how much to order.

Figure 10.1: Bar codes used for inventory management

PART NO. (P)	50327-MG9-0000	
		
QUANTITY (Q)	420	SUPPLIER CAPITOL PLASTICS 333 VAN CAMP ROAD BOWLING GREEN, OH. 43402.
		COLOR BLK
DESCRIPTION BATTERY CUSHION UPPER		
DELIVERY INFORMATION FORM		SERIAL 00134
		
(0000000000)		

PART NO. (P)	50328-MG9-0000	
		
QUANTITY (Q)	120	SUPPLIER CAPITOL PLASTICS 333 VAN CAMP ROAD BOWLING GREEN, OH. 43402.
		COLOR BLK
DESCRIPTION BATTERY CUSHION LOWER		
SERIAL (S)	00134	DELIVERY INFORMATION FORM
		
	(0000000000)	

Real World Scenarios: Toys “R” Us—Dealing with Fads in the Toy Business

A major problem in the toy industry is identifying when fads begin and end. There is a long history of fads including GI Joes, Smurfs, Furbies, and Transformers, which have recently made a comeback. In many cases, these items are hot one year and gone the next. Toys “R” Us carries more than 20,000 different items. To maximize profits, the company must be sure it maintains just the right amount of each item. One way it does this is by using computers to monitor sales data and to order (or stop ordering) as point-of-sale (POS) demand information indicates. This information is transmitted each day to the company’s headquarters where it is automatically monitored. Thus, when demand for scooters picks up, the computers can catch the trend and began placing larger orders. Likewise, drops in sales when a fad has ended can be caught and replenishment orders halted.

Perpetual Inventory Systems

A **perpetual inventory system** continuously monitors inventory levels. It is also known as a continuous review system. Under such a system, inventory transactions are recorded as they occur. If the number of transactions is small, this recording can be done by hand, which is how inventory was recorded before computerized systems. This non-computerized approach makes sense if there are only a handful of items to inventory. Computers, however, have made the process much easier and faster for a larger number of items. For example, grocery stores and retailers such as Walmart use point-of-sale systems that record



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To keep track of inventory, retailers use a point-of-sale (POS) system that records each transaction as the items are read by a bar code scanner.

the transaction as each item is read by the bar code scanner. As at Toys “R” Us, this information is passed along to the supplier, so replenishment can take place. An ATM is another example of a perpetual inventory system; this system updates the balance in a patron’s bank account as withdrawals are made. Debit cards are one way for the bank to move the money from the user’s account at the time of transaction. These cards also allow the bank to determine if there is sufficient money to cover the transaction, which is good for the bank and the retailer.

Companies use bar codes for raw material and work-in-process inventories as a way to computerize these inventory records. The bar codes shown in Figure 10.1 are used on a component part ordered from a supplier. Using bar codes or other similar technologies allow the firm to be constantly aware of inventory levels. When inventory drops to a predetermined level (the order point) an order for more can be generated. Often, this ordering is completed automatically by the same computer system that maintains the inventory records. The quantity

ordered is usually a fixed amount, often the economic order quantity, which is discussed later in this chapter.

Periodic Inventory Systems

For the continuous review system to work, it is necessary to know the inventory level constantly, and to have a supplier who will replenish inventory at any time. In this way, when the order point in the continuous review system is reached, an order can be sent and delivery can take place.

When a company does not know the level of inventory or the supplier will only deliver at a specific interval such as monthly or weekly, the periodic review system can be used. A meaningful order cannot be placed if the on-hand level of inventory is unknown. Also, ordering after the supplier's order window has closed will not generate an immediate response. The supplier will not process and deliver the order until the order window is open.

To be effective, the periodic review system is designed to place an order only when on-hand inventory information is available and the supplier is willing to deliver, in other words, when the order window is open. The local concrete plant uses cement, which it stores in large tanks. It takes a physical inventory only on Monday because it is time consuming, so it does not know if or how much it needs to order except on Monday. The storage tanks at most gasoline service stations are refilled on a preset schedule, for example, once each week on Friday. Monitoring inventory continuously and placing an order on Saturday does not help because the delivery will not be made until the following Friday.

In these cases, the order point must be set at a level that will allow the company to meet expected demand until the next order window occurs plus demand during the lead time. If the on-hand inventory is less than this order point, an order is generated that will push on-hand inventory back to a predetermined level. The periodic review system, also called the fixed order interval system, can be run without a computerized system to monitor inventory levels, but it is more likely to run out of stock because the system is unable to react quickly to changes in demand because inventory level is not continually monitored. If the firm wishes to keep the chance of stockouts low, it must increase the level of safety stock inventory.

Aggregate Performance Measures

Inventory represents a tremendous capital investment. In general, the companies that can operate with less inventory are the companies that operate more efficiently. Aggregate performance measures can be used to judge how well a company is utilizing its inventory resources. One of the most common measures is **average inventory investment**—the dollar value of a company's average level of inventory. The primary disadvantage of this measure is that it makes comparisons between companies difficult. For example, larger companies will generally have more inventory than smaller companies. Thus, a large multinational company may have a larger average inventory investment than a small business, but the larger company may be using its inventory more efficiently.

Inventory turnover ratio is a measure that allows for better comparison among companies. This ratio is calculated by comparing a company's sales to its average inventory investment, as follows:

$$\text{Inventory turnover} = \text{annual cost of goods sold} / \text{average inventory investment}$$

The inventory turnover ratio indicates how many times the inventory turns over or is sold during one year. Because this ratio is a relative measure, companies of different sizes can be more easily compared. In general, a company with a higher turnover ratio will be using its inventory more efficiently. For example, automobile companies using just-in-time (JIT) often have very high inventory turnover ratios of 30 or more, while those not using JIT may be in the range of 6 to 12. JIT is providing only the items that are needed at the time they are needed. One disadvantage of this ratio is that figures among industries may not be comparable.

A measure closely related to inventory turnover is **days of inventory**. The calculation procedure is as follows:

$$\text{Days of Inventory} = \text{average inventory investment} / (\text{annual cost of goods sold} / \text{days per year})$$

The days of inventory indicate approximately how many days of sales can be supplied solely from inventory. The lower this value, the more efficiently inventory is being used. In general, inventory turnover can be converted to days of inventory by using the following calculation:

$$\text{Days of inventory} = \text{days per year} / \text{inventory turnover rate}$$

ABC Classification

Interestingly, companies do not need to keep accurate track of all inventory items. For instance, certain parts may have a relatively low value and be used infrequently; those items can often be monitored very loosely. On the other hand, high-value and high-usage items must be tracked carefully and continuously. **ABC analysis** has been developed to determine which inventory items should receive the highest level of control. By multiplying the dollar value of each item by its annual usage, a dollar usage value can be obtained. Dollar usage follows the Pareto Principle (see Chapter 4) in that typically, only 20% of all the items account for 80% of the total dollar usage, while the remaining items typically account for only 20% of the dollar



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ABC analysis is used to determine which inventory items should receive the highest level of control. This method focuses efforts where the payoff is highest.

usage. This principle leads to the ABC classification, which is based on focusing efforts where the payoff is highest.

After calculating the dollar usage for each inventory item, the items are ranked by dollar usage, from highest to lowest. The first 20% of the items are assigned to class A, as shown in Table 10.1. These are the items that warrant closest control and monitoring through a perpetual inventory system. Accurate inventory records are important, and there is a high potential for cutting costs through careful buying and close scrutiny of safety stocks.

Table 10.1: ABC classification of inventory items

Item	Annual Demand	Unit Cost	Annual Dollar Usage	% Annual Dollar Usage	Cumulative % Annual Dollar Usage	Classification
1	5,000	\$30	\$150,000	48.91	48.91	A
2	200	450	90,000	29.34	78.25	A
3	2,000	10	20,000	6.52	84.77	B
4	800	20	16,000	5.22	89.99	B
5	1,000	10	10,000	3.26	93.25	B
6	1,200	5	6,000	1.96	95.21	C
7	1,300	4	5,200	1.69	96.90	C
8	2,500	2	5,000	1.63	98.53	C
9	3,500	1	3,500	1.14	99.67	C
10	500	2	1,000	0.33	100.00	C
			306,700			

The next 30% of the items are classified as B items. These deserve less attention than A items. Finally, the last 50% of stocked items are C items. These have the lowest dollar usage and can be monitored loosely, with larger safety stocks maintained to avoid stockouts.

10.3 Economic Order Quantity Model

Inventory decisions involve trade-offs: Keeping more inventory may decrease the amount of stockouts as well as reduce the ordering and set-up costs, but keeping more inventory requires more investment, storage, and management costs. One model that seeks to minimize these costs is the **economic order quantity (EOQ)**. The EOQ model is concerned primarily with the cost of ordering and the cost of holding inventory, but the basic model can be expanded to address several issues.

Costs of Ordering and Holding

One major component of cost associated with inventory is the cost of replenishing it, usually called **ordering cost**. If a part or raw material is ordered from outside suppliers, an ordering cost is incurred. Conversely, parts, subassemblies, or finished products may be produced in-house. In that case, ordering cost is represented by the costs associated with changing over equipment from producing one item to producing another, and is referred to as **set-up cost**. To simplify, this text will refer to both ordering costs and set-up costs as ordering costs.

Ordering costs may include many different items. Some of these will be relatively fixed, and others may vary. It will be important to differentiate between the ordering costs that do not change much and those that are incurred each time an order is placed. For example, suppose a company currently places orders for a given part with its supplier five times per year. If, instead, the company ordered six times per year, which costs would probably change (variable costs), and which would probably not (fixed costs)? The general breakdown between fixed and variable ordering costs is listed in Table 10.2.

Table 10.2: Fixed costs and variable costs

Fixed Costs	Variable Costs
Staffing costs (payroll, benefits, etc.) Office furniture and equipment	Shipping costs Cost of placing an order (phone, postage, order forms) Cost of lost production during set-up Cost of materials used during set-up Receiving and inspection costs

Although it costs money to replenish inventory, it also costs money to hold that inventory. Such inventory holding costs, also called **carrying costs**, may include costs paid for storage space, interest paid on borrowed money to finance the inventory, and any losses incurred due to damage or obsolescence. Once again, it is important to differentiate between fixed and variable costs of holding inventory. To understand this difference, consider this question: What happens if an inventory level is increased by one unit? Which costs would not change (fixed costs), and which costs would change (variable costs)? The general breakdown for inventory holding is shown in Table 10.3.

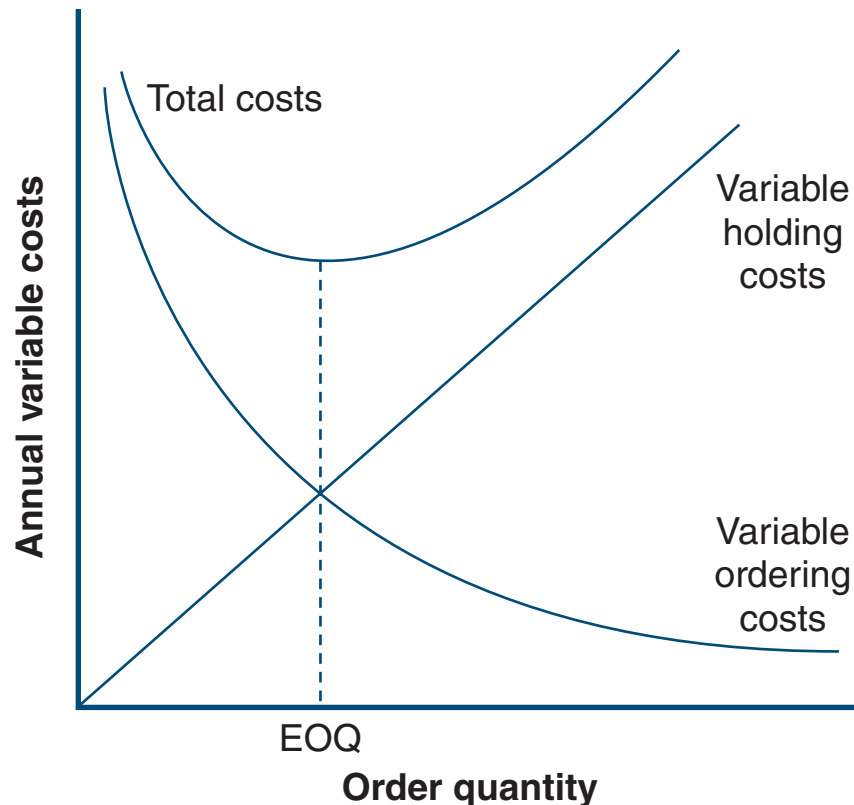
Table 10.3: Inventory holding

Fixed Costs	Variable Costs
Capital costs of warehouse Taxes on warehouse and property Costs of operating warehouse Personnel costs	Cost of capital in inventory Insurance on inventory value Losses due to obsolescence, theft, spoilage Taxes on inventory value Cost of renting warehouse space

In the next section, the most basic approach to determining order quantity, called the economic order quantity (EOQ) model, is discussed. The goal of firms using the EOQ model is to minimize the total annual costs of ordering and holding inventory by varying the order quantity. Only variable costs are considered because fixed costs are not affected by short-term variation in order quantity. To understand EOQ, it is important to understand the differences between the fixed and variable costs that are listed above. Also, it is important to realize that the division between fixed and variable costs may change depending on the context. If additional personnel must be hired, staffing costs may be considered variable.

Ordering cost and holding cost can be described with the analogy of two children sitting on a seesaw. When one goes up, the other goes down, and vice versa. This trade-off appears to present somewhat of a quandary: If an effort is made to decrease total annual variable holding costs, total annual variable ordering costs will increase—and vice versa. A solution to this dilemma is to combine the two costs as total annual variable costs and minimize only that cost. As Figure 10.2 indicates, there is just one point at which total costs are minimized. The order quantity associated with that point is called the economic order quantity (EOQ).

Figure 10.2: Total annual variable costs

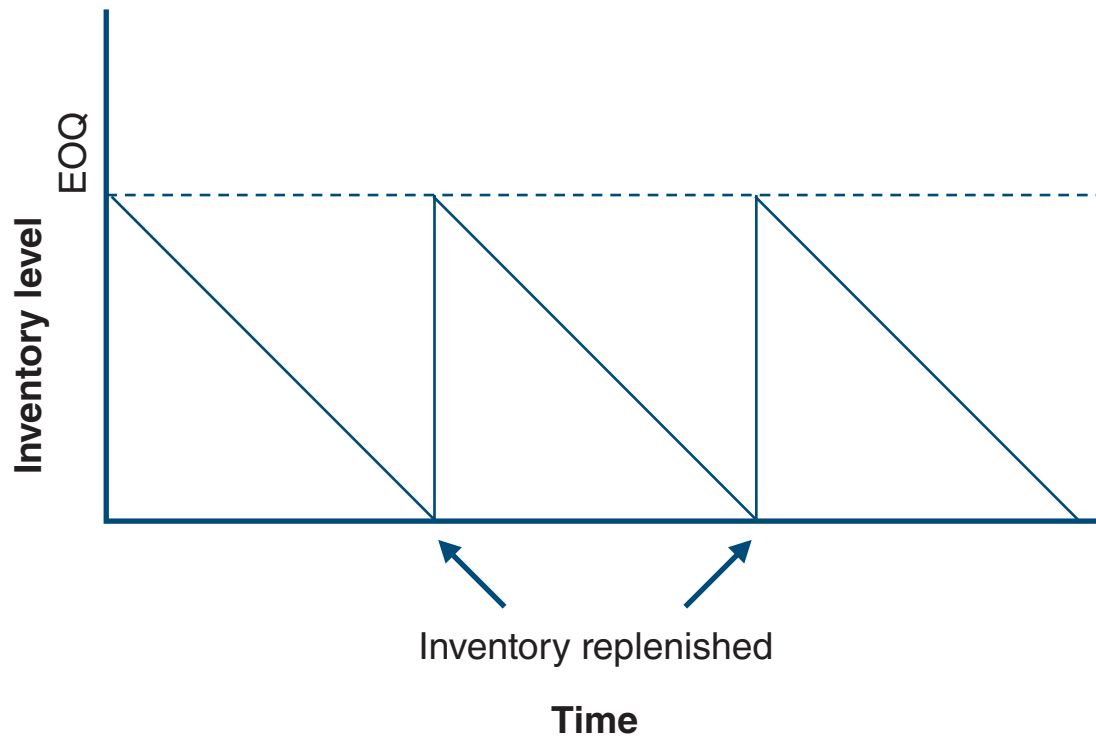


Assumptions of the EOQ

Figure 10.2 indicates the economic order quantity point. A set of simplifying assumptions can be made because the EOQ model is a simplification of real ordering processes. Those assumptions are described here. Later, variations of the EOQ model will be considered when some of these assumptions are not necessary.

1. *Constant known demand:* The first assumption is that demand is fairly stable, or constant, and reasonably known.
2. *Cost per unit is not dependent on order quantity:* Most things can be purchased at a lower cost per unit if they are purchased in larger quantities. For instance, large sizes of laundry detergent usually cost less per ounce than smaller sizes. This example, however, makes purchase cost a variable cost—something for which the EOQ model does not account. Thus, the assumption is that purchase cost per unit remains the same, regardless of whether the amount is one, 100, or 1,000 units each time.
3. *Entire order delivered at once:* This assumption relates to how inventory is replenished. Gradually building up inventory, as would happen in a clothing factory, is one possibility. As a particular model of jacket is produced, the inventory of that jacket builds up gradually. Another possibility is for all units in an order to arrive at one time, which is what happens when a retail store orders from a factory. The factory ships an entire order of the jacket at one time and the store's inventory is replenished all at once. It is this latter, instantaneous replenishment that is assumed by the EOQ. This assumption, combined with the assumption of constant demand, results in the inventory pattern depicted in Figure 10.3.
4. *Ordering and carrying costs known and independent:* The final assumption is that the variable costs of ordering and carrying inventory are known. In many cases, such costs can be determined from company records or from the accounting department; however, they are sometimes not readily available and must be estimated. Also, the assumption is made that these two costs are not related in any way, and that only variable costs are effected by the order quantity.

These assumptions may seem restrictive, and possibly unrealistic. Recall, however, that the EOQ model is the basic starting point. This model may be altered to relax some of these assumptions—and more closely match reality.

Figure 10.3: Basic EOQ inventory pattern

Mathematics of EOQ

Stating the EOQ formula in mathematical terms requires the use of variables to represent the parameters. The variables are:

D = demand rate (units/year)

Q = order quantity or lot size (units)

C_o = variable ordering cost (\$/order)

C_h = variable holding cost (\$/unit/year)

Once again, please note that these are the variable costs and that the variable ordering costs will represent additional costs incurred when another order is placed. Holding costs also include only the variable costs associated with keeping one more unit in inventory. These variables are stated as cost per unit per year because the model is illustrating annual costs.

Another way of stating inventory holding costs is to divide C_h into two components. The elements that make up variable holding costs depend on the number of units in inventory and the value of each unit. In most instances, it is possible to state inventory holding cost, C_h , as a percentage of unit cost per year (\$/year). The greatest part of this percentage is

accounted for by capital tied up in the inventory. Because capital cost is usually stated as a percentage, it is especially convenient to state holding cost in this form. To do so, the following variables are used:

v = cost or value of item (\$/unit)

r = holding-cost percentage of unit value (\$/\$/year)

Then $C_h = vr$.

Regardless of how many units are ordered at a time, the number of orders can be determined by dividing annual demand, D , by the order quantity, Q . Thus,

$$\text{Orders placed per year} = \frac{D}{Q}$$

Since the cost per order is C_o , annual variable ordering costs can be easily calculated as follows:

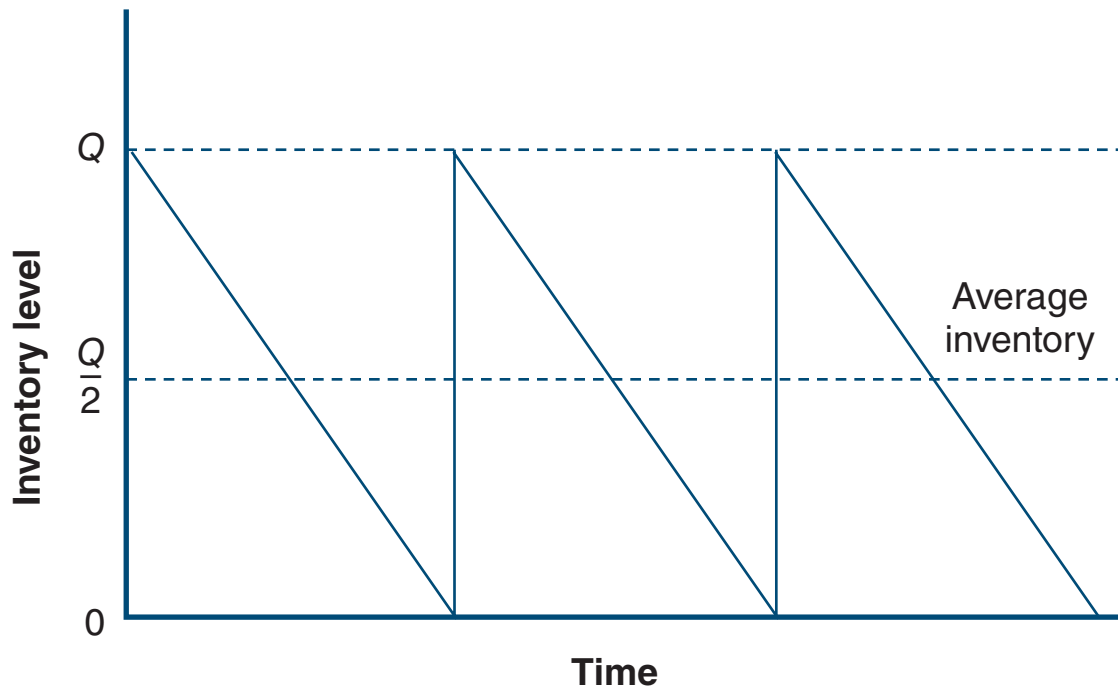
$$\text{Annual variable ordering costs} = \frac{D}{Q}C_o$$

Annual Variable Holding Costs

Notice in Figure 10.3 that if the order quantity is set equal to the EOQ, the theoretical inventory pattern is a straight line between the EOQ and zero. Remember the assumption is that demand is constant over time, which makes the drawdown of inventory a straight line. Suppose, instead, that the variable Q represents the quantity ordered each time. In that case, the maximum inventory level would be Q , assuming inventory is replenished just as it reaches zero. Minimum inventory would still be zero. This fluctuation in the inventory level makes the calculation of annual holding costs somewhat difficult because there will be a different number of units in inventory at any one time. To make matters worse, each unit will be in inventory for a different length of time—some for a very short period, others longer. There is also an easier, but equivalent, way to determine annual holding costs.

The method used to determine annual holding costs is based on average inventory level. Because inventory follows a uniform pattern, with a maximum of Q and a minimum of zero, the average level will be halfway between the maximum and minimum values, or $Q/2$. In terms of the number of units in inventory, and the time each unit spends there, the fluctuating system shown in Figure 10.3 is actually equivalent to maintaining $Q/2$ units at all times, as shown in Figure 10.4. This simplifies the calculation of annual variable holding costs to:

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

Figure 10.4: Average inventory*Economic Order Quantity Formula*

Total annual variable costs will be the sum of holding costs and ordering costs. Using the formulas noted above, this will be:

$$\text{Total annual variable costs} = \frac{Q}{2}C_h + \frac{D}{Q}C_o$$

The economic order quantity will be the point at which the total cost function is minimized. An easy way to find this point is by identifying that the EOQ occurs where annual holding costs and annual ordering costs are equal, as shown in Figure 10.2. In mathematical terms, this is

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

Note that Q^* has been used to designate the optimal value of Q , which is the economic order quantity. Solving the above equation for Q^* we obtain

$$(Q^*)^2 = \frac{2DC_o}{C_h}$$

and by taking the square root of each side,

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

Problem

Bill Green, general manager for Poolco, a company that provides home pool maintenance services in the Los Angeles area, is responsible for developing inventory policies regarding all items the company stocks. One item that he is expected to monitor is a clarifying agent that is added to pool water to improve its clarity. This item costs \$5/gallon. Variable costs of storing it in inventory amount to 25% of unit cost per year. Paperwork and shipping costs for placing an order are \$10 per order. Each year the company uses an average of 500 gallons, a rate that is not expected to change. How many gallons should be ordered each time to minimize total annual variable costs?

$$C_h = vr$$

$$C_h = 5(0.25) = \$1.25 \text{ per unit/year}$$

$$EOQ = \sqrt{\frac{2DC_o}{C_h}} = \sqrt{\frac{2(500)(10)}{1.25}}$$

$$EOQ = 89.44 \text{ gallons}$$

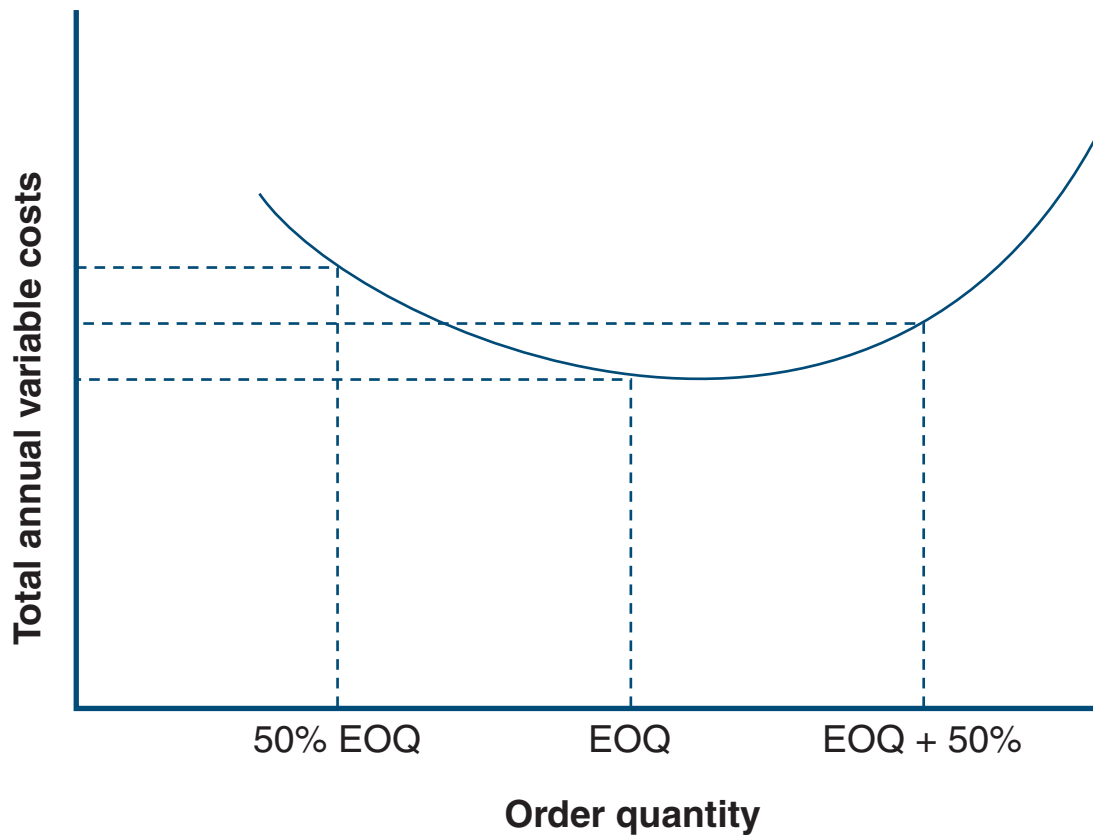
Because an order must be placed for whole gallons, Bill would round this down to 89 gallons per order.

Sensitivity of the EOQ Value

The EOQ in the preceding example did not result in an even value; rounding down to the nearest whole number still provided a result that was somewhat unusual. It would be far more likely that Bill Green could order 90 gallons at a time than 89. But, suppose this clarifying agent is only available in 55-gallon drums. In that case, the closest order quantity would be two drums, or 110 gallons. What impact will this have on total annual variable costs if Poolco must order 110 gallons of clarifying agent at a time?

The total annual variable cost function is rather “flat” around the EOQ, as shown in Figure 10.5. That is, order quantities can be varied considerably from the EOQ, especially above it, without greatly increasing costs.

Figure 10.5: Total annual cost curve near the EOQ

**Problem**

Suppose Bill Green of Poolco wants to determine how much higher costs will be if he orders in lots of 110 gallons instead of the 89.44 gallons determined by the EOQ formula.

The total annual variable costs for the EOQ of the preceding example will be

$$\begin{aligned}
 \text{Total annual variable costs} &= \frac{Q}{2} C_h + \frac{D}{Q} C_o \\
 &= \frac{89.44}{2} (\$1.25) + \frac{500}{89.44} (\$100) \\
 &= \$55.90 + \$55.90 = \$111.80
 \end{aligned}$$

(continued)

Problem (continued)

However, by changing Q to 110, the total annual variable costs will become

$$\begin{aligned}
 \text{Total annual variable costs} &= \frac{Q}{2} C_h + \frac{D}{Q} C_o \\
 &= \frac{110}{2} (\$1.25) + \frac{500}{110} (\$10) \\
 &= \$68.75 + \$45.45 \\
 &= \$114.20
 \end{aligned}$$

Thus, the cost increase incurred by ordering in quantities of 110 gallons at a time is only \$2.40, or 2.15% more than the total annual variable costs of ordering EOQ quantities.

As this example indicates, the cost consequences of varying from the EOQ are not very great. The EOQ value should be an estimate that indicates approximate minimum-cost order quantities, not a value that must be used exactly.

Holding and ordering cost figures for the EOQ formula are usually obtained from accounting when operations does not have the information available. In some companies, accounting is responsible for determining inventory holding and ordering costs. Such costs are often buried as part of overhead expenses and are not readily available for use in calculating the EOQ. Determining these figures often requires that departments work together to calculate numbers that are realistic.

Quantity Discounts: An EOQ Model Variation

Starting with the basic EOQ model, it is possible to develop other models that have less restrictive assumptions, or are appropriate for other situations. One assumption from the example is that purchase price remained the same regardless of how many units were purchased. In reality, this is usually not true. For example, things usually cost less per unit, when purchased by the case rather than individually. An entire truckload generally will cost less than each case. Order quantities directly influence the purchase price of an item.

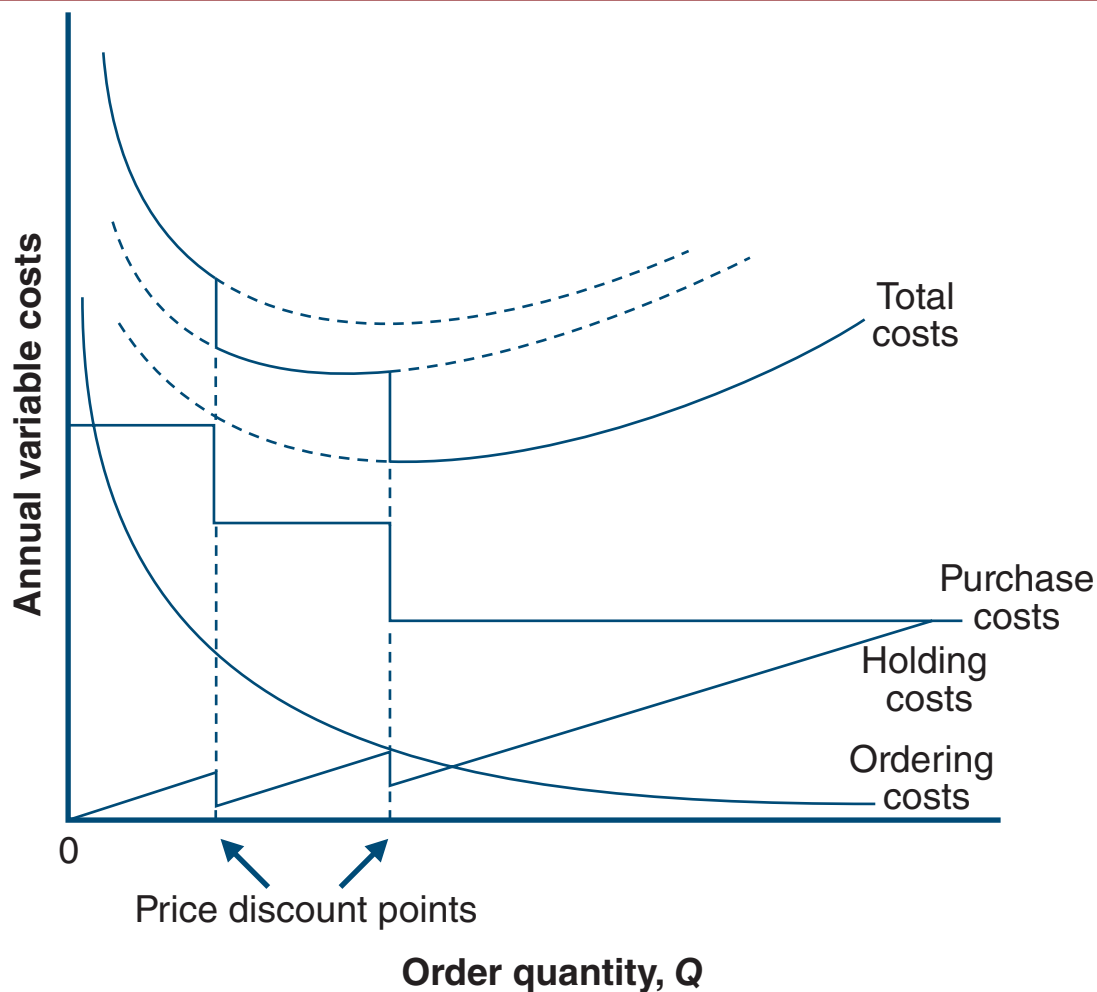


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Items usually cost less, per unit, when purchased in bulk. Therefore, the order quantity directly influences the purchase price of an item.

Incorporating quantity discounts into the order quantity calculations requires modification of the total-cost calculation to include purchase cost—which had not been included in the previous example because it was a fixed cost. The total annual cost of purchasing an item may vary due to quantity discounts. The optimal answer cannot be found by substituting numbers into a formula, as in the example for the EOQ. This situation occurs because quantity discounts occur in a stepwise manner, as shown in Figure 10.6. When this pattern of purchase costs is used to calculate total annual purchase cost and then combined with ordering and holding costs, the total-cost curve appears (also shown in Figure 10.6). A step-by-step procedure is required to determine the order quantity that generates the lowest total annual costs.

Figure 10.6: Total annual cost with quantity discounts



The procedure for calculating lot sizes when a quantity discount is available is based on using the unit cost, v , and holding-cost percentage, r , to calculate holding cost. In other words, $C_h = vr$

Notice that as the unit purchase cost varies, so does the holding cost.

Step 1. Start with the lowest unit price. Calculate the holding cost, C_h , for this price, and then determine the EOQ. If this EOQ is “feasible”—in other words, if it falls in the range of order quantities required for that unit price—this is the optimal order quantity. Stop here.

If the EOQ is not feasible, determine the minimum order quantity required for that unit price, and calculate the total annual variable costs (holding cost, ordering cost, and purchase cost) associated with that minimum order quantity. Proceed to step 2.

Step 2. For the next higher unit price, calculate holding cost, and determine EOQ. If the EOQ is feasible, then calculate its total annual variable costs, and compare this with the total annual variable costs for order quantities calculated previously. That order quantity with the lowest total annual variable costs will be optimal. Stop here.

If the EOQ is not feasible, repeat this step until a feasible EOQ is found; then calculate its associated total annual costs, and compare these costs with all total annual costs previously calculated. The order quantity with the lowest associated total annual variable costs will be optimal.

Problem

Bill Green of Poolco has learned that the supplier of the clarifying agent will begin offering quantity discounts according to the following schedule:

Gallons Ordered	Unit Price
54 or less	\$5.00
55–274	4.80
275–549	4.60
550 or more	4.50

Bill wonders whether he should change his lot size for ordering the clarifying agent. To answer his question, he proceeds through the steps described previously.

Step 1. Calculate the holding cost and EOQ corresponding to the lowest unit price. This unit price will be \$4.50, and its associated holding cost is $(0.25)(\$4.50) = \$1.125/\text{gallon}/\text{year}$.

$$EOQ = \sqrt{\frac{2(500)(10)}{1.125}}$$

= 94 gallons (rounding to the nearest whole number)

(continued)

Problem (continued)

However, this is not feasible because at least 550 gallons must be the ordered quantity each time an order is placed with the supplier to obtain the \$4.50 unit price. Recall that Bill's supplier requires an order of at least 550 gallons to have the price be \$4.50. Because this solution is not feasible, the second part of Step 1 is implemented. The minimum order quantity required to obtain the unit price of \$4.50 is used to calculate the total annual variable costs (holding cost, ordering cost, and purchase cost). In this case, that minimum order quantity is 550 gallons.

$$\begin{aligned}
 \text{Total annual variable costs} &= \frac{Q}{2} C_h + \frac{D}{Q} C_o + Dv \\
 &= \frac{550}{2} \$1.125 + \frac{500}{550} \$10 + 500(\$4.50) \\
 &= \$309.38 + \$9.09 + \$2,250.00 \\
 &= \$2,568.47
 \end{aligned}$$

Step 2. For the next higher unit price, calculate holding cost, and determine EOQ. This next higher unit price will be \$4.60, obtained by ordering between and including 275 and 549 gallons each time.

Holding cost will be $(0.25)(\$4.60) = \$1.15/\text{gallon}/\text{year}$ and

$$\begin{aligned}
 EOQ &= \sqrt{\frac{2(500)(10)}{1.15}} \\
 &= 93 \text{ gallons}
 \end{aligned}$$

This also is not feasible because 93 is not between or including 275 to 549 gallons required for the \$4.60 unit price. Thus, taking the minimum value in that range of 275, the associated total annual variable cost is calculated.

$$\begin{aligned}
 \text{Total annual variable} &= \frac{Q}{2} C_h + \frac{D}{Q} C_o + Dv \\
 &= \frac{275}{2} \$1.15 + \frac{500}{275} \$10 + 500(\$4.60) \\
 &= \$158.13 + \$18.18 + \$2,300.00 \\
 &= \$2,476.31
 \end{aligned}$$

Because the EOQ for this unit price was not feasible, the process moves to the next higher price of \$4.80/gallon. Its holding cost will be \$1.20/gallon/year, and the EOQ is 91 gallons.

This EOQ is feasible, so the total annual variable costs are calculated.

$$\begin{aligned}
 \text{Total annual variable} &= \frac{Q}{2} C_h + \frac{D}{Q} C_o + Dv \\
 &= \frac{91}{2} \$1.20 + \frac{500}{91} \$10 + 500(\$4.80) \\
 &= \$54.60 + \$54.95 + \$2,400.00 \\
 &= \$2,509.55
 \end{aligned}$$

(continued)

Problem (continued)

Total annual variable costs calculated are compared in the following table:

Order Quantity (Gallons)	Total Annual Variable Costs
550	\$2,568.47
275	2,476.31
91	2,509.55

The lowest-cost order quantity will be 275 gallons, and Poolco should change its lot size for the clarifying agent accordingly.

10.4 Stockouts and Safety Stock

In the EOQ model, it is assumed that demand is constant and known, however, in practice this is rarely true for independent demand items. This section discusses ways to ensure that uncertainty about actual demand does not result in lost sales. The process begins by determining the point at which inventory must be replenished.

Order-Point Determination

In the calculations thus far, it was assumed that inventory would be replenished just as the inventory level hit zero. Thus, the minimum inventory level was treated as zero. In most situations, the replenishment of inventory requires some advance notice. For example, a company that orders materials from a supplier must account for (1) the time it takes that order to reach the supplier's offices, (2) the time to fill the order, and (3) the shipping time. This is called **lead time**. Failing to account for lead time can cause an organization to run out of inventory. This situation is known as a **stockout**. Any time a stockout occurs, a disruption in production, idle employees, and unhappy customers will likely be the result. Most companies try to avoid stockouts if possible.

The easiest way to account for lead time is to use what is called an **order point**. An order point is simply a level of inventory at which an order should be placed, accounting for lead time

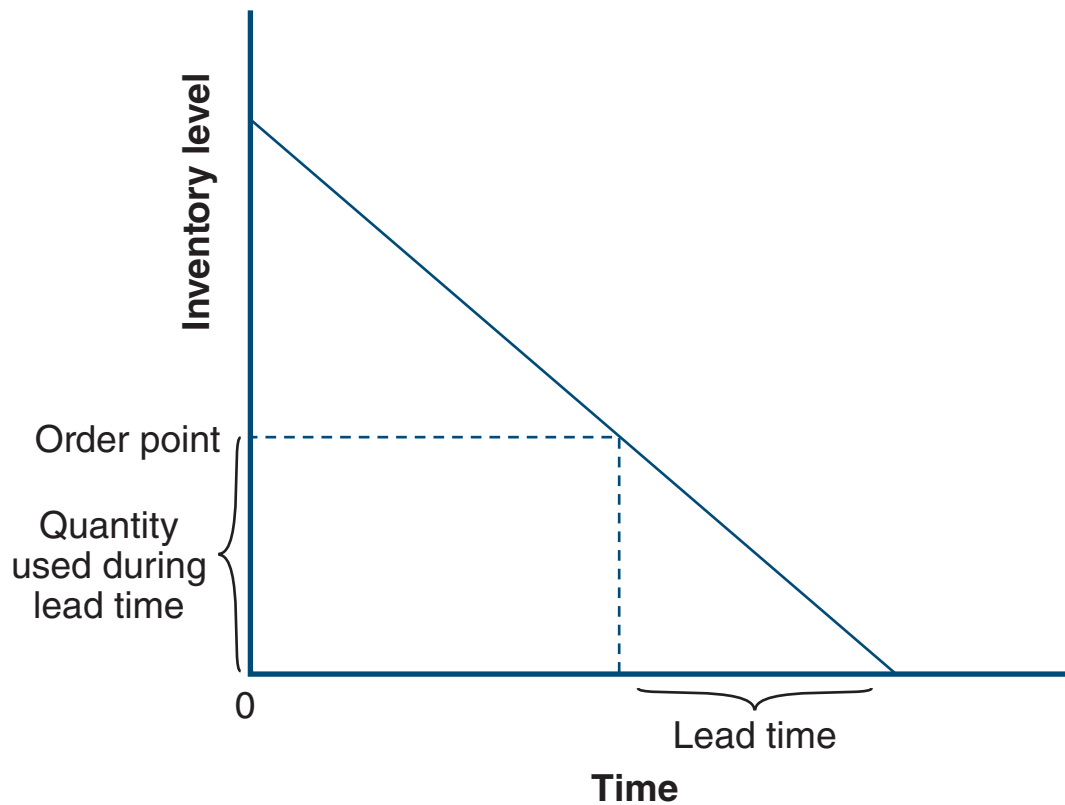


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Apple experienced a stockout when the iPhone 4 was released. A stockout occurs when an organization underestimates demand or has delays in production which lead to late delivery of the product.

and safety stock, so that the order will arrive before a stockout occurs. Figure 10.7 shows how the order point is determined.

Figure 10.7: Order-point determination



The graph depicted in Figure 10.7 indicates that the order point should be a level of inventory that will be sufficient to last throughout the lead time, with inventory reaching zero just as the order arrives. Mathematically, the order point can be determined as follows.

d = daily demand rate (units/day)

L = lead time (days)

Then the order point, OP , can be determined by using the formula given below.

$$OP = dL$$

Problem

Suppose that Poolco wants to determine the order point for its clarifying agent. Daily demand is two gallons per day (500 gallons per year/250 working days per year). Suppose that the lead time for ordering the clarifying agent is 10 working days. The order point is:

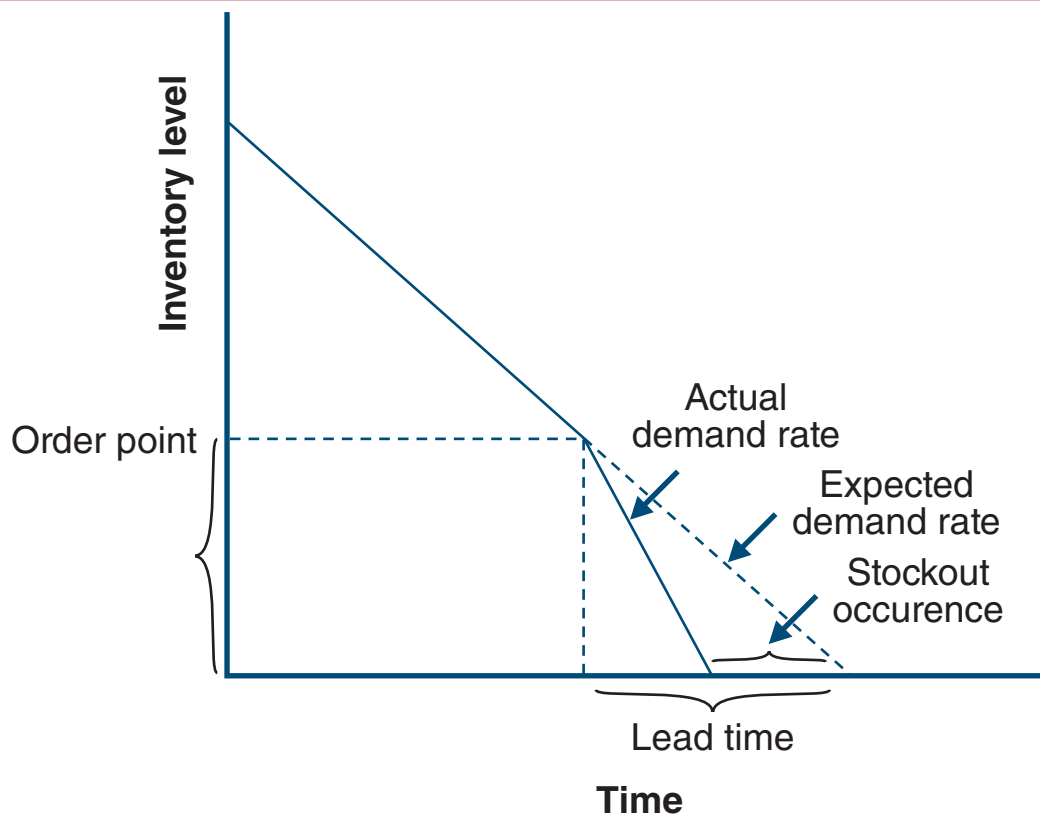
$$\begin{aligned}OP &= dL \\&= 2(10) \\&= 20 \text{ gallons}\end{aligned}$$

Therefore, when only 20 gallons are left in inventory, an order for more should be placed. That order should arrive just as inventory reaches zero.

Safety Stock

The order-point determination described in the prior section works well when demand rate and lead time are known. It is much more common to find that demand and lead time are both variables. If either lead time or demand (or both) is less than expected, there will be no problem when the order arrives; some inventory will remain. But if either demand or lead time (or both) exceed our expected values, then a stockout will occur because inventory will hit zero before the order arrives, as shown in Figure 10.8. There is no margin of safety in the preceding order-point calculation.

Figure 10.8: Stockout occurrence



To avoid stockouts, most companies add a **safety stock**, which is an extra amount of inventory, to the order-point calculation so that

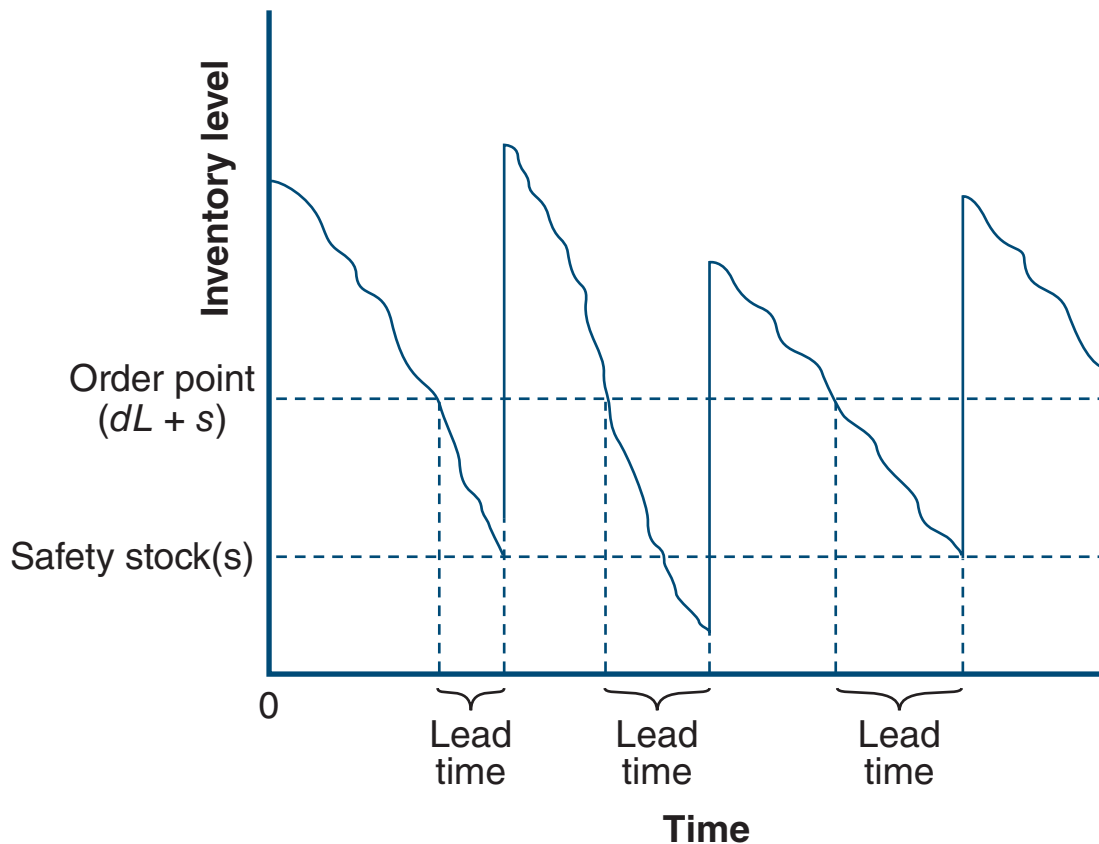
$$OP = dL + s$$

where

s = safety stock

This adds a buffer of inventory that can be expected to remain when an order is received. Instead of allowing inventory be depleted before an order comes in, it only decreases to s , the amount of safety stock, as shown in Figure 10.9. Due to demand and lead-time variability, more or less stock may remain at any given time. The expectation is that this buffer of safety stock will be sufficient to prevent most stockouts.

Figure 10.9: Inventory level with safety stock



Service Level

No matter how much safety stock a company carries, there is always some chance that a stockout will occur due to unusually high demand or an unexpected long lead time. It is not possible for a company to avoid stockouts altogether. The trade-off is easy to understand. If a company adds more safety stock its inventory holding cost will increase, but

the probability of a stockout and lost sales decline. What is the “right” amount of safety stock to balance these two possibilities? Many companies choose to address this trade-off by selecting a level of stockouts that they are willing to accept, which is commonly called the service level. **Service level** is the percentage of replenishment orders that are received before a stockout occurs. For instance, a 95% service level would indicate that 95% of all orders placed to replenish inventory are received before a stockout occurs. But in 5% of the cases, inventory will hit zero before the order is received.

Inventory levels can greatly influence a company’s ability to fulfill customer orders. For companies such as Lands’ End, rapid delivery of customer orders can be so important that the extra cost incurred by carrying higher inventory is worthwhile. In other organizations, though, customers may not always expect the item they want to be in stock.

Because service level is so important, its determination must involve not only operations but also marketing, and sometimes finance. Considering the role of rapid delivery in the organization’s competitive strategy, and balancing this role against the added costs of carrying extra inventory, can allow an organization to determine the service level that will best meet its needs.

Determination of service level is a managerial decision that must be based on many factors. A company that competes for quality of service may choose a service level of 99% or higher. Another company may be in an industry where meeting customer demand from inventory is not important. For the latter, a service level of 80% or lower may be acceptable. Once the service level has been determined, a company may proceed to calculate its safety stock.

With the rapid expansion of online shopping, an organization does not need to have the item on hand because the customer will not leave the store with the item. These companies can ship goods directly from the producer or the producer’s distribution center.

Calculating the Safety Stock

The assumption will be made that demand during the lead time follows the normal probability distribution, which is often realistic and allows the use of the commonly available normal probability tables. The normal probability distribution is described by a mean and a standard deviation. For this problem, these values are

$$D_L = \text{average demand during lead time}$$

$$\sigma_L = \text{standard deviation of demand during lead time}$$

The safety stock necessary to obtain a desired service level can be calculated as

$$\text{Safety stock} = z\sigma_L$$

where

z = number of standard deviations from the mean required
to obtain desired service level

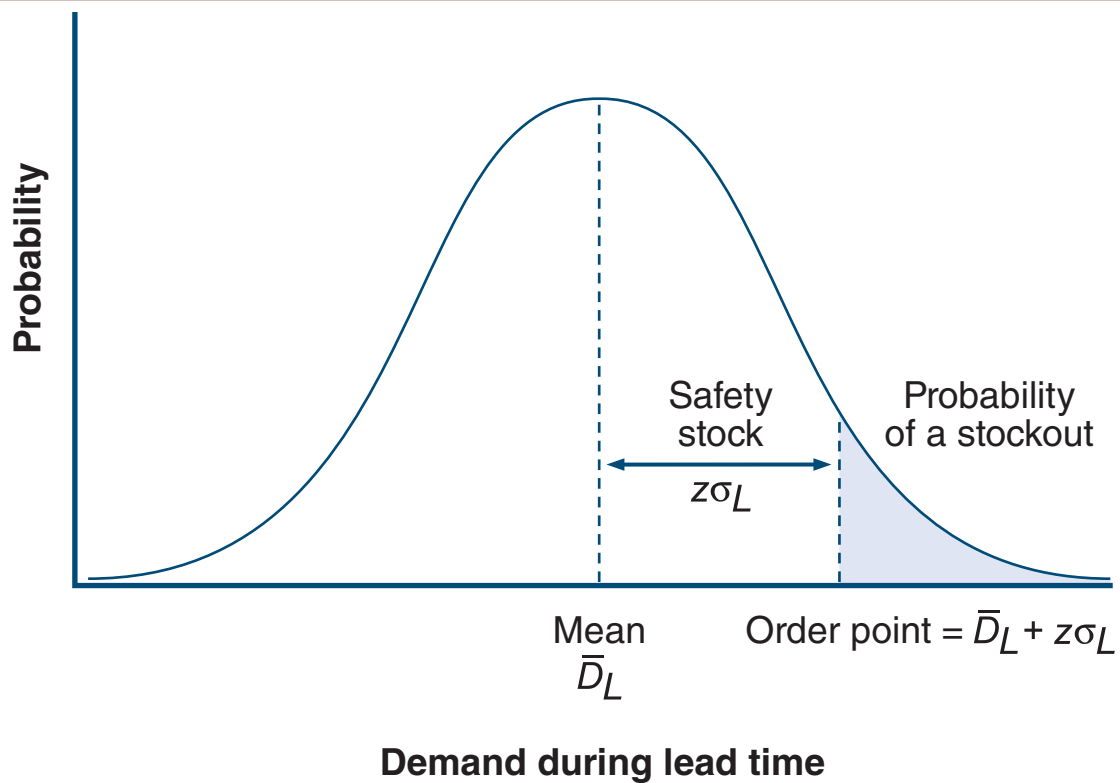
The order point is then

$$OP = D_L + \text{safety stock}$$

$$= D_L + z\sigma_L$$

As Figure 10.10 indicates, the service level—or probability of no stockout—will be equal to the area under the normal curve up to $D_L + z\sigma_L$. The value of z is determined by the desired service level.

Figure 10.10: Normal probability distribution



Problem

A company has average demand during the ordering lead time that is normally distributed with a mean of 35 and a standard deviation of six. What safety stock and order point are necessary to obtain approximately a 90% service level?

Referring to the normal distribution table in Table 10.4, the probability closest to 0.90 is 0.8997, which is in the 1.2 row and 0.08 column. Thus, a z value of 1.28 is needed to obtain a 90% service level.

$$\begin{aligned}\text{Safety stock} &= z\sigma_L \\ &= 1.28(6) \\ &= 7.692 \text{ or } 8\end{aligned}$$

$$\begin{aligned}\text{Order point} &= D_L + \text{safety stock} \\ &= 35 + 8 \\ &= 43\end{aligned}$$

Table 10.4: Areas under the standardized normal curve from $-\infty$ to $+z$

z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.5000	0.5040	0.5080	0.512	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359
0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753
0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517
0.4	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879
0.5	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224
0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549
0.7	0.7580	0.7611	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852
0.8	0.7881	0.7910	0.7939	0.7967	0.7995	0.8023	0.8051	0.8078	0.8106	0.8133
0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8315	0.8340	0.8365	0.8389
1.0	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621
1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830
1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015
1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177
1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319
1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633
1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767
2.0	0.9772	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817
2.1	0.9821	0.9826	0.9830	0.9834	0.9838	0.9842	0.9846	0.9850	0.9854	0.9857
2.2	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.9890
2.3	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916
2.4	0.9918	0.9920	0.9922	0.9925	0.9927	0.9929	0.9931	0.9932	0.9934	0.9936
2.5	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952
2.6	0.9953	0.9955	0.9956	0.9957	0.9959	0.9960	0.9961	0.9962	0.9963	0.9964
2.7	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972	0.9973	0.9974
2.8	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981
2.9	0.9981	0.9982	0.9982	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986
3.0	0.9987	0.9987	0.9987	0.9988	0.9988	0.9989	0.9989	0.9989	0.9990	0.9990

10.5 Fixed-Order-Interval Model

The EOQ model is most often used when a company can continuously monitor its inventory level to determine when the order point is reached. Continuous monitoring may not be reasonable or necessary. In such cases, orders are often placed at a fixed interval of time, which is when the inventory is reviewed. In spite of this difference, the EOQ model can be used to determine an optimum interval for reviewing and replenishing inventory. From any given review interval, a policy can be developed to determine how much to order.

Review Interval

Refer to the EOQ model and Figure 10.3. The time that elapses between replenishments depends on the order quantity, or lot size. The model can be used to determine the number of replenishment orders placed per year. In a periodic review system, the opposite will occur. That is, the time between reviews, or the **review interval (R)**, will determine average order quantity because the annual demand must be met during one year. If orders are placed frequently, then each order will be smaller. Infrequent ordering means larger lot sizes.

Recall, though, that there is still a trade-off between variable ordering costs and variable inventory holding costs. Thus, the review interval that is chosen can directly affect total annual variable costs.

Fortunately, most of what is needed to calculate that optimal interval, R , was learned when the EOQ was calculated. This is because the relationship between order size and order interval means that an economic order quantity will also produce an economic order interval. In other words, the optimal review interval is simply the interval that results in ordering an EOQ quantity each time. This order interval is the EOQ divided by demand rate, D .

$$\text{Optimal review interval, } R = \frac{EOQ}{D}$$

Problem

The Hunziker Hardware Store carries many different items, ranging from nails and screws to appliances and hot-water heaters. While the firm has a point-of-sales data collection system, it doesn't make sense for them to order different items at different times, especially when the items are relatively low cost and are provided by the same supplier. Instead, the company would like to determine a review interval at which all items ordered from one regular supplier can be checked and ordered at one time.

One group consists of brass items, such as screws, hinges, and cupboard handles. Because all such items are similar in cost and demand level, they have been grouped together. The annual demand rate for these items is 10,000 units per year. Ordering cost is \$25 per order, and holding cost is \$0.02 per unit per year. Using the above data, the EOQ is determined as follows: (continued)

Problem (continued)

$$EOQ = \sqrt{\frac{2(10,000)(25)}{0.02}}$$

$$= 5,000 \text{ units}$$

Based on this, the review interval is:

$$R = \frac{EOQ}{D}$$

$$= 5,000/10,000$$

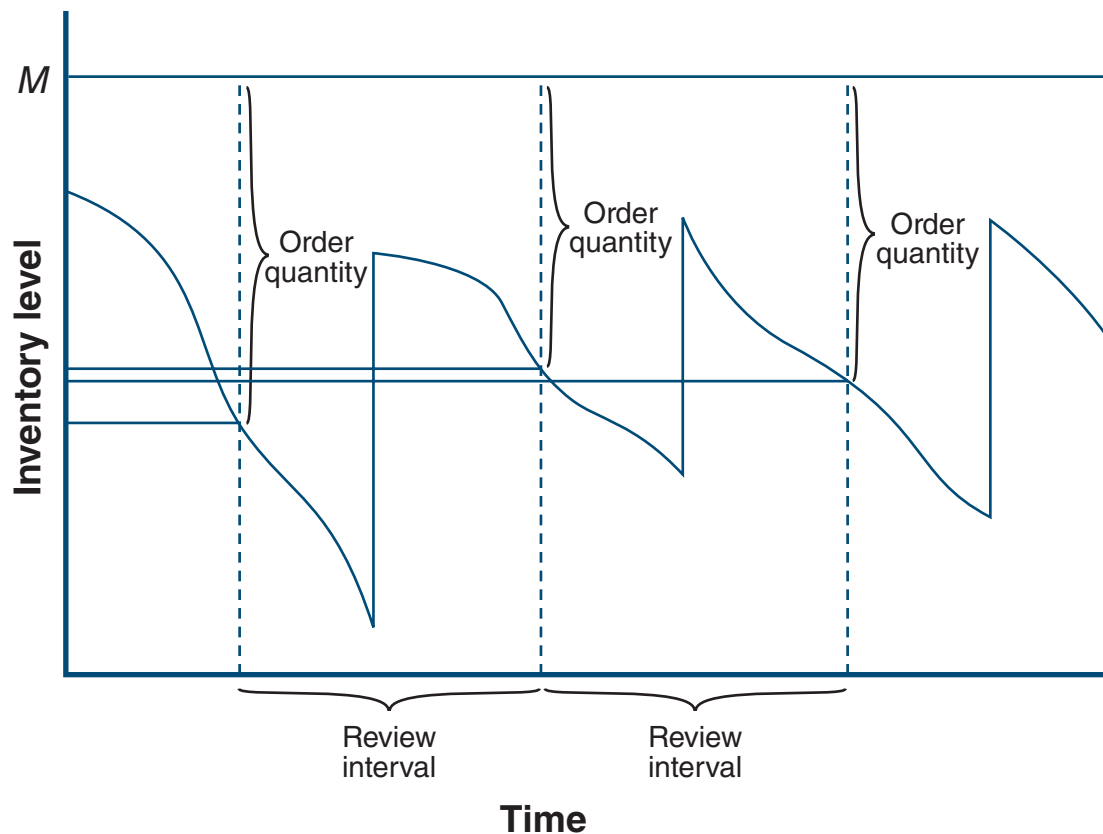
$$= \frac{1}{2} \text{ year}$$

The Hunziker Hardware Store should review the inventory levels of these small hardware items twice per year and order the required quantity of each.

Order-Up-to Level

The next value to be determined in a periodic review system is how much to order. Under continuous review, a replenishment order is always placed when inventory reached the order point. However, in a periodic review system, the inventory level at the time of review will vary, as depicted in Figure 10.11.

Figure 10.11: Order-up-to level in a periodic review system

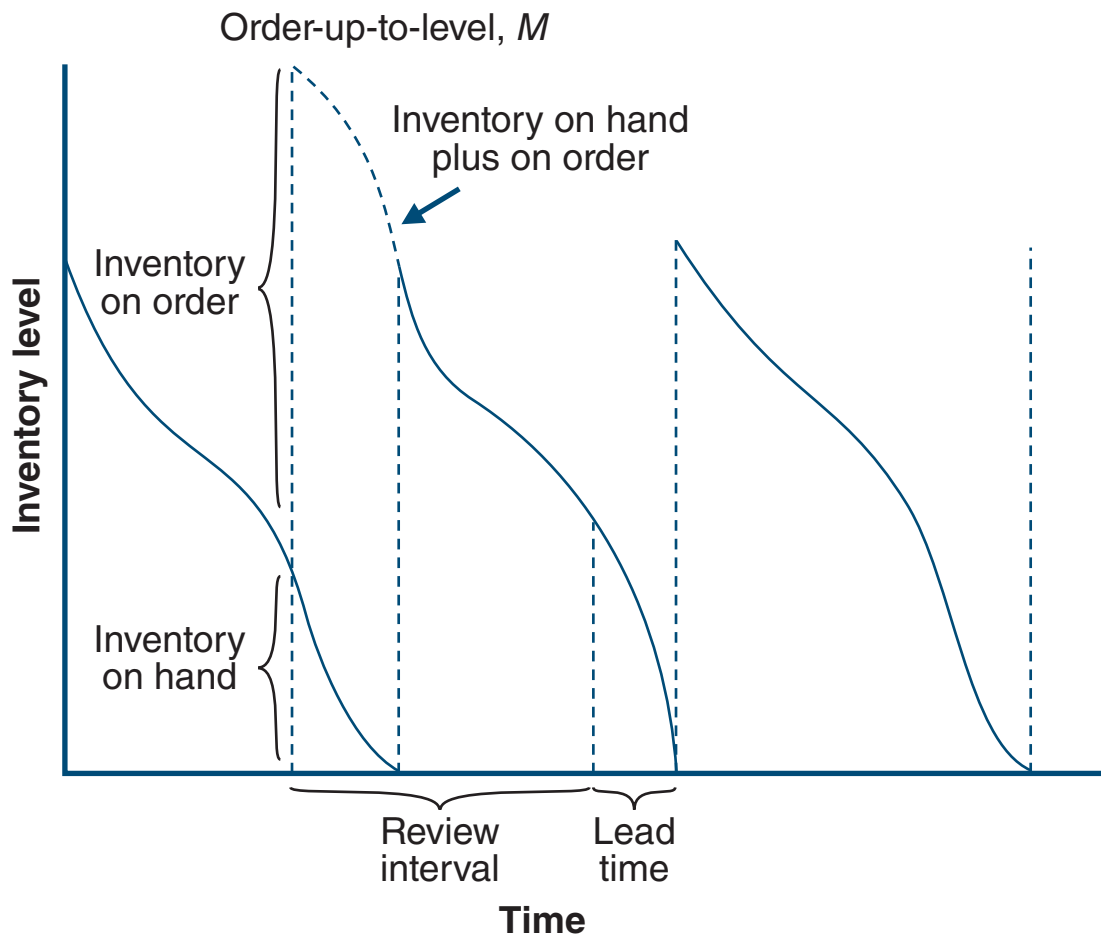


If a constant amount were ordered each time, it would be very difficult to recover from a low inventory level. Instead, the quantity ordered must increase inventory to a level sufficient to cover anticipated demand before the next order is received. This is called the **order-up-to level**, or M . A diagram of an order-up-to level is shown in Figure 10.11.

Another difference between continuous and periodic review systems relates to the period of time that must be covered by an order. Inventory levels are monitored continuously and an order is placed whenever the inventory reaches the order point if stock is continuously reviewed. A periodic review system only reviews inventory at the review point; once an order has been placed the inventory will not be checked again until the next review point. Each order must contain a sufficient amount to cover expected demand during the review interval plus demand during the lead time, as shown in Figure 10.12, or a stockout will occur. If the review interval, R , and the lead time, L , are stated for one year, then the order-up-to level to cover demand during the review interval plus the lead time must be:

$$M = D(R + L)$$

Figure 10.12: Period of time an order must cover



Problem

It was determined in the previous example that the review interval for the common group of brass hardware items will be one-half of one year for all items in that group. One of the hardware items in that group is a brass gate hinge that has a demand of 1,000 units per year. Lead-time is one-tenth of one year. What should the order-up-to level be for this hardware item? We can use the preceding formula to calculate this level as follows:

$$\begin{aligned} M &= D(R + L) \\ &= 1,000(0.5 + 0.1) \\ &= 600 \text{ units} \end{aligned}$$

This means that when the hardware store reviews inventory for this group of items, it should order enough of the brass gate hinges to bring on-hand plus on-order inventory up to 600 units. For example, suppose that during the semi-annual inventory review, 100 brass gate hinges are in inventory. In that case, 500 brass gate hinges (600 – 100) should be ordered.

Safety Stock for the Fixed-Order Interval Model

The order-up-to level described above is similar to the order point in a continuous review system. As with the basic order-point calculation, the preceding order-up-to formula does not include safety stock. Because of the nature of periodic review systems, safety stock is probably more important and necessary than in continuous review systems. It will also be larger. Under a continuous review system, the lead time following an order was the period of time when a stockout could occur. Therefore, safety stock was calculated using the standard deviation of demand during the lead time. However, with a periodic review system, a stockout could theoretically occur at any time between review periods and during the lead time. Thus, safety stock for a periodic review system must be calculated based on the standard deviation of demand during the review interval plus the lead time. Except for this modification, the calculation is the same as for a continuous review system; safety stock will now be added to the order-up-to level.

Problem

The brass gate hinge discussed in the previous example had an order-up-to level of 600 with no safety stock. Suppose that demand during the review interval plus the lead time has a standard deviation of 100 units. What must the order-up-to level be set at to obtain a 95% service level if demand is equally distributed?

From the normal probability tables (Table 10.4), a probability of 95% corresponds to a z value of 1.645. Therefore, the safety stock will be:

$$\begin{aligned} \text{Safety stock} &= z\sigma_{R+L} \\ &= 1.645(100) \\ &= 164.5 \text{ or } 165 \text{ hinges} \end{aligned}$$

(continued)

Problem (continued)

Adding this to the expected demand during the review interval plus the lead time (the M calculated in the preceding example), the new order-up-to level becomes:

$$\begin{aligned} M &= D(R+L) + \text{safety stock} \\ &= 1,000(0.5 + 0.1) + 165 \\ &= 765 \end{aligned}$$

Chapter Summary

- The purposes served by inventory include meeting expected demand, absorbing demand and lead time fluctuations, decoupling production processes, hedging against price increases, and protecting against delivery disruptions.
- The economic order quantity model is based on the assumptions that demand is constant and known. Cost per unit does not depend on order quantity, and an entire order is delivered at one time.
- Quantity discounts mean that the total-cost curve is discontinuous, requiring a stepwise procedure to find the minimum cost point.
- The order point is determined from expected demand during the lead time.
- If demand during the lead time is variable, then a safety stock may be added to the order point, based on a probability distribution.
- In a perpetual inventory system, inventory level is constantly monitored, and orders are placed whenever necessary.
- In a periodic system, inventory is checked at regular intervals, and enough is ordered to bring inventory up to a desired level.

Case Studies**Alliance Supermarkets**

Alliance Supermarkets has been using a point-of-sale (POS) system for some time to track its inventory. The system uses a laser scanner to read the universal product code (UPC) on each item at the checkout container. The UPC is a number that uniquely identifies the product on which it appears. Currently, Alliance is using the UPC information to update inventory records for each item. Although the system has greatly improved the company's ability to replenish inventory promptly, the company still has some problems. For example, sudden changes in demand for a particular item can catch the company by surprise as it bases inventory replenishment on historical demand patterns. Further, demand patterns and preferences may vary from one store to another depending on the customers served by each, but the inventory system groups all demand information together and treats each store equally. Finally, the manufacturers that make the products stocked by Alliance Supermarkets are always pressuring Alliance to help them target appropriate customers for special promotions and sales.

The chief information officer (CIO) of Alliance realizes that much more could probably be done with the data collected from its POS system. For example, the company could analyze the relationship between each product's sales and weather patterns. It is even

possible to analyze an individual customer's buying habits and identify instances when a customer may be persuaded to try a different brand of a certain product.

Suppose you have been asked to study this situation and suggest possible new and innovative uses for the information generated by the POS system. Ideally, these ideas should help Alliance better serve its customers by ensuring that adequate quantities of each item are available, that costs are kept low, and that customers are made aware of new products that may interest them.

1. What information may help Alliance reduce costs while providing better service?
2. If purchase information can be obtained on individual customers, what new approach could be used by Alliance?

Discussion Questions

1. Describe the reasons why an organization would keep inventory.
2. What are the different types of inventory, and what are the uses of these types?
3. Describe the perpetual and the periodic inventory systems. How are they different? Are there circumstances in which one system better than the other?
4. How does the ABC classification system work, and how does it help to control costs?
5. The economic order model is based on the trade-off between holding and ordering costs. Describe these two different types of costs and how each depends on order size.
6. How do quantity discounts impact the decision about amounts ordered?
7. What is safety stock, and what is the basis for determining the amount of inventory to hold as safety stock?

Problems

1. Fast-Mart is a discount retailer that uses a POS system to maintain continuous inventory records. A particular item has an average annual demand of 40,000 units. It costs \$25 to replenish inventory of that item, which has a value of \$10 per unit. If the inventory carrying cost is 20% of the unit value, how many units should be ordered each time to minimize total annual variable costs?
2. Suppose Fast-Mart has found that the item described in Problem 1 has a lead time of two working days. If the company operates 250 days per year, determine the order point for that item.
3. The Fill-er-Up gas station has found that demand for its unleaded gasoline is fairly constant and uniform at the rate of 100,000 gallons per year. Fill-er-Up must pay \$100 for shipping per order of gasoline, which it currently buys for \$3.75/gallon. Inventory carrying cost is 10% of unit cost per year. How many gallons should be ordered at a time?
4. Suppose that in Problem 3, Fill-er-Up's underground storage tanks can hold only 10,000 gallons of unleaded gasoline. What is the extra cost incurred by ordering this quantity each time instead of the EOQ?

5. The Slick Oil Company buys crude oil from a supplier that has recently offered the following quantity discounts:

Barrels Ordered	Price per barrel
1–999	\$110
1,000–2999	\$105
3,000 or more	\$102

If inventory holding cost is 25% of the unit price and it costs \$100 for each order, regardless of order size, how many barrels should Slick order each time to satisfy its annual demand of 10,000 barrels?

6. Burger-Farm is a fast-food restaurant that buys hamburger buns from a local bakery. Those buns are used at the rate of 50,000 per year. The baker has just offered Burger-Farm the following quantity discounts:

Buns Ordered	Price per bun
1–999	\$.030
1,000–1,999	\$.028
2,000 or more	\$.027

If it costs Burger-Farm \$1 for each order placed and the inventory holding cost is 25% of the unit cost, determine how much should be ordered each time to minimize total annual variable costs.

7. Referring to Problem 6, suppose Burger-Farm is limited to ordering only one week's worth of buns at a time due to storage space limitations and spoilage problems. What impact will this have on total annual variable cost?
8. The Young Professionelle Shoppe is a boutique for professional women. A periodic system is used to control inventory. Suppose that a certain blazer has an average annual demand of 1,000 units. The ordering cost is \$5, and the inventory carrying cost is \$10 per unit per year. What should the review interval be for this blazer?
9. Suppose that the Young Professionelle Shoppe in Problem 8 prefers to review its inventory weekly. Estimate the effect on total annual variable costs of following this procedure.
10. A discount retail store uses a periodic inventory system through which each item's inventory level is reviewed twice monthly. Suppose it has been determined that a particular item has an average annual demand of 6,000 units, with a standard deviation of 100 units per month. If lead time is one-half month and the store wants a service level of 85%, determine the order-up-to level for this item.
11. The Goodstone Tire Store has been using a periodic review system to control its inventory. For one tire model, the annual demand averages 5,000 units. In the

- past, inventory was reviewed so that the review interval plus lead time was one month. The standard deviation of demand during this period was 50 units. The company is now planning to use a continuous review system. Suppose lead time is one week and the standard deviation of demand during lead time is 10 units. Compare the safety stock necessary under periodic review with what would be necessary for continuous review at a 90% service level.
12. An inventory clerk at the Fargo Machine Tool Company has just calculated the EOQ for one of the steel alloys used by this company as 500 pounds. However, the lead time for ordering this steel is four months, and the company uses 150 pounds per month—an order point of 600 pounds—which is greater than the EOQ. Can you help this inventory clerk figure out how to handle this case, in which order point exceeds the EOQ?
 13. West Coast Furniture Distributors is a company that buys large quantities of furniture from manufacturers at low prices, and then sells to the public at prices below what most furniture stores charge. To minimize costs, West Coast Furniture uses EOQ for ordering. For one particular model of sofa, the manufacturer has now agreed to cover part of the shipping costs, reducing the ordering cost from \$50 per order to \$40. At the same time, West Coast Furniture has been able to obtain lower interest rates on borrowed money, reducing its inventory carrying cost from 25% of unit cost to 20%. The company expects to sell 1,225 of these sofas per year and pays \$100 to purchase each one.
 - a. What effect will the preceding changes have on the EOQ?
 - b. What effect will the preceding changes have on the total annual costs of ordering and carrying inventory?
 14. Referring to Problem 13, how many days' worth of demand will be covered by each order of sofas?
 15. A company maintains inventories of the following nine items. Based on this information, determine which are A items, B items, and C items.

Item #	Value	Annual Usage
209	\$14.76	2,000
4914	5.98	15,000
37	1.15	297,000
387	6.48	6,000
3290	2.17	6,000
235	75.00	300
48	23.95	7,000
576	4.32	5,000
14	932.00	1,000

Key Terms

ABC analysis A classification system for inventory items so that 20% of items (A items) that account for the top 80% of dollar usage receive the most attention.

average inventory investment The dollar value of a company's average level of inventory.

carrying costs The variable costs associated with keeping inventory.

days of inventory Indicates approximately how many days of sales can be supplied solely from inventory.

economic order quantity (EOQ) An amount to order at one time that minimizes total annual cost of ordering and holding inventory.

inventory turnover ratio Indicates how many times during one year the inventory turns over, or is sold.

lead time The difference between the time the order is placed and the delivery of the product.

order point A level of inventory at which an order should be placed.

ordering cost The variable costs associated with replenishing inventory.

order-up-to level The level to which a replenishment order should bring on-hand plus on-order inventory within a periodic review inventory control system.

perpetual inventory system A system in which inventory level is continuously monitored and a replenishment order placed when inventory reaches a predetermined level.

review interval The time between one review of inventory and the next in a periodic review inventory control system.

safety stock An extra amount added to the order point as a buffer against stockout possibilities.

service level The percentage of inventory replenishment orders that are received before a stockout occurs.

set-up cost The costs associated with changing over equipment from producing one item to producing another.

stockout A condition that occurs when no more inventory of an item is available.