

# INDEPENDENT DEMAND INVENTORY MANAGEMENT

# 7

## LEARNING OBJECTIVES

After completing this chapter, you should be able to:

- 7.1 Describe the types of inventory
- 7.2 Explain the functions of inventory
- 7.3 Interpret the costs, risks, and value of inventory
- 7.4 Calculate the EOQ and reorder point under various demand and lead time conditions
- 7.5 Discuss the importance of inventory management performance measures

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## ➔ MANAGING INVENTORY IN THE CLOUD AT USA CYCLING ←

In 2009, Colorado-based USA Cycling, the official governing body for all U.S.-member competitive cycling, decided to switch from a manual inventory system to an on-demand, cloud-based system. Today, USA Cycling can track the movement of all its inventories among the group's 66,000 members around the world. Keeping track of bikes and associated equipment is not easy. "From our headquarters in Colorado Springs, we were always trying to figure out how much clothing we needed to have in Belgium and Italy and where to pull those items from," says Gregory Cross, director of USA Cycling. "It wasn't unusual for us to get a call from a rider in Europe, asking us what we wanted him to do with a set of racine wheels that he'd had for a few months because we'd lost track of them."

Up until mid-2009, USA Cycling used spreadsheets to record incoming and outgoing items and then shared the information with employees via email. Once the company made the decision to change to the cloud-based system, it brainstormed with employees and surveyed the applications on the market. "We talked to quite a few of the coaches and found out what they wanted and needed," says Cross. "We also worked closely with our director of athletics to brainstorm ideas and figure out how we wanted this system to behave and operate." In the end, it selected an on-demand system due to its customization capabilities and ease of use.

With no previous system in place, USA Cycling started from scratch. To ensure accuracy with its new system, Cross and his team had to count everything and enter each item into the system. "Getting the information into the system for the first time was the hardest part of the implementation—in fact, we're still finding items [around the world] that need to be accounted for," explains Cross. "An athlete will say 'Oh, I have this bike or piece of clothing' and we have to go enter it into the system manually."

Today, when shipments arrive in Colorado Springs, the items are sorted and the information is uploaded to the system. Staff members around the world can immediately view the information and place orders. The time savings compared to the old system are huge. "Now they can just pull up the system, log in, and see where everything is," says Cross.

When a team is prepping for a race, Cross can create shipments of desired clothing and nutritional items. He knows exactly where everything is, how many items USA Cycling has, and can ship whatever the team needs when it needs it, with minimal time investment.<sup>3</sup>

## INTRODUCTION

For most organizations, inventory represents a sizeable investment in both time and money. It can also be an extremely complex issue for most manufacturers, as well as their supply chain trading partners. In many cases, businesses may not even be aware of the impact their products and product deliveries have on their customers' products and inventory levels. Thus, managing inventory in the right ways can have beneficial impacts on customer service, competitiveness, and costs.



See how one small business modernized its inventory management capabilities

Every company carrying inventories must consider their impact on the firm—too little inventory can lead to stockouts, plant shutdowns, and disgruntled customers. Too much inventory can mean storage problems, inventory write-downs, and excess inventory carrying costs. Thus, inventories can be considered good, but they can also mean higher costs. Operations managers seek to find an optimal balance, then, between inventory effectiveness and cost.

Consequently, managers need to develop effective inventory control procedures. The chapter begins with a discussion of inventory terms, and then presents a number of inventory control topics and procedures. Over time, companies must seek to continuously improve competitiveness through improvements in these inventory management activities. It then becomes necessary to design inventory management performance measures, and these are discussed as the final topic of the chapter.

## TYPES OF INVENTORIES

### 7.1 Describe the types of inventory

As shown in Table 7.1 and described below, inventories can be classified as either raw materials, work-in-process, finished goods, or maintenance, repair, and operating (MRO) supplies.

Most companies have some or all of the following types of inventories. **Raw materials** consist of purchased parts and other materials that are delivered by suppliers and used in the manufacture of finished products or services. Raw materials might include lumber, automobile assemblies, nuts and bolts, plumbing supplies, and hamburger buns. They can be delivered to warehouses or stock areas located within the facility. **Work-in-process** (WIP) inventories are items in some intermediate stage of processing at the firm. When raw materials are put into the production process, they become WIP inventories. They can be stored on the factory floor or possibly on automated overhead racks that move throughout the facility. **Finished goods** are completed products ready for delivery to customers. When WIP inventories are completed, they become finished goods and can be stored at the firm or in geographically dispersed distribution centers. **Maintenance, repair, and operating supplies** (MRO) are purchased items consumed in-house or used to support manufacturing and service processes. Examples include machine tools and maintenance supplies, cleaning supplies, and office supplies.

Each of these inventories creates costs, but they can also add significant value for the firm. All four play important roles in the production of high-quality, low-cost products, smoothly running equipment, and satisfied employees and customers. The objective of inventory management, then, should be to find an optimal on-hand quantity for each inventory item, considering its cost, availability, and importance. The various functions of inventory are described next.

## FUNCTIONS OF INVENTORY

### 7.2 Explain the functions of inventory

While inventories keep factories and services running and ensure high levels of customer service, managers must decide how much inventory is enough and which functions of inventory are required. Table 7.2 lists the functions of inventory, and these are listed below.

**Table 7.1** Types of Inventories

Type	Description
<b>Raw materials</b>	Purchased items used in manufactured products or services.
<b>Work-in-process</b>	Items in some intermediate stage of processing at the firm.
<b>Finished goods</b>	Completed products ready for delivery to customers.
<b>Maintenance, repair, and operating supplies</b>	Purchased items consumed in-house or used to support manufacturing and service processes.

**raw materials** Purchased parts and materials that are delivered by suppliers and used in the manufacture of finished products or services.

**work-in-process** Items in some intermediate stage of processing by the firm.

**finished goods** Completed products ready for delivery to customers.

**maintenance, repair, and operating supplies** Purchased items consumed in-house or used to support manufacturing and service processes.

Inventories are held and used by the firm for a number of reasons. **Anticipation inventories** allow demand to be met during periods of expected high demand, such as the busy Christmas selling season or the period of time following a big advertising promotion. **Cycle inventories** are created when the firm purchases or produces in quantities large enough to last until the next purchase or production period. If a company purchases a month's worth of components, this is a cycle inventory. Another example of a cycle inventory would be the economic order quantity, which will be discussed later in this chapter. **Hedge inventories** are used when companies stockpile items to protect against price increases or supply shortages. Airlines, for example, might stockpile fuel if they think the prices are



**Table 7.2**

The Functions of Inventory Function	Description
<b>Anticipation inventories</b>	Allows demand to be met during periods of expected high demand.
<b>Cycle inventories</b>	Created when the firm purchases or produces a quantity large enough to last until the next purchase or production period.
<b>Hedge inventories</b>	Used when companies stockpile items to protect against price increases or supply shortages.
<b>Safety stocks</b>	Held to satisfy demand when unforeseen supplier or manufacturing problems occur, or when demand is higher than expected.
<b>Transportation inventories</b>	Owned by the firm and in-transit, either in-bound to the firm or out-bound to the firm's customers.

going up. The United States continues to stockpile oil in the Strategic Petroleum Reserve for the same reason. The United States started the reserve in 1975 after the 1973–1974 oil embargo, and as of September 2014, there were 691 million barrels of oil held underground in the reserve's salt dome formations near the Gulf of Mexico. This represents approximately 37 days of oil and \$65 billion at 2014 consumption rates and market prices.<sup>4</sup> **Safety stocks** enable the firm to satisfy demand when unforeseen supplier or manufacturing problems occur or when demand is higher than expected. Firms might hold safety stocks of raw materials, WIP, finished goods, or MRO items. And finally, **transportation inventories** are inventories owned by the firm that are in-transit either in-bound to the firm or out-bound to the firm's customers. If a firm purchases parts from a supplier, for example, and chooses to use its own vehicle to transport the shipment to the firm, then the parts become transportation inventory.

As shown here, inventories can serve several functions, all of which create inventory carrying costs. To reduce these costs, operations managers look to reduce any excess inventories within these various functions. Inventory costs are further discussed below.

## INVENTORY COSTS, RISKS, AND VALUE

### 7.3 Interpret the costs, risks, and value of inventory

Inventory costs are considerable for many organizations, such as manufacturing firms and big-box retailers like Walmart. Particularly during the recent economic recession, reducing inventory costs became a financial necessity at many businesses, since as inventory costs are reduced, profits are increased on a dollar-for-dollar basis (but *only* if stockout costs are

**anticipation inventories** These are held so that demand can be met during periods of expected high demand.

**cycle inventories** Created when the firm purchases or produces a quantity large enough to last until the next purchase or production period.

**hedge inventories** Used when companies stockpile inventories to protect against price increases or supply shortages.

**safety stocks** These inventories are held to satisfy demand when delivery or production problems occur, or when demand is higher than expected.

**transportation inventories** These inventories are owned by the firm and are in-transit either in-bound to the firm or out-bound to the firm's customers.



See how stockouts of antimalaria drugs are being reduced in Africa

avoided). Unfortunately, the risk of stockouts does tend to increase as inventory levels are reduced, due to the uncertainties of customer demand and supplier deliveries. Inventory costs can be broken down, as shown in Table 7.3, and are described below.

**Order costs** are the administrative costs associated with purchasing items. These include the labor and paperwork costs to select a supplier, write a purchase order, process it through the company, transmit it to the supplier, receive the order, inspect it, and then process the invoice. In a recent survey of government offices by the U.S. General Services Administration, it was determined that the average order costs of the respondents were about \$111. Interestingly, the same study also found that average order costs were only \$29 when office credit cards (or p-cards) were used, and the time required to process paperwork transactions was reduced by two to six weeks.<sup>5</sup> **Inventory carrying costs** are the costs associated with storing inventories. These include warehouse rent or depreciation costs, maintenance and energy costs, warehouse personnel costs, handling costs, equipment depreciation costs, and shrinkage costs. These costs can be quite large for firms with a network of company-owned warehouses or distribution centers. Additionally, inventory carrying costs include lost opportunity costs and capital costs, which are what the firm gives up by having capital tied up in inventory and warehouses. For example, if the firm normally makes a 15% return on its invested capital, then this would be included in the inventory carrying costs. **Stockout costs** occur when the internal or external demand for items cannot be met. Stockout costs include the current lost sale, lost goodwill, or damage to the firm's reputation, lost future sales, and possibly the cost to process a backorder. Backordering incurs administrative costs, expediting costs, and shipping costs. Stockout costs can be very costly to both the buyer and the supplier, particularly if the item is a critical part needed by a highly valued buyer. Generally, stockout costs can be very difficult to estimate, since damage to a firm's reputation and the potential for lost future sales cannot easily be determined. Because of this, managers often resort to using trial-and-error methods when setting safety stock levels. Finally, **purchase cost** is the actual cost of the items bought from suppliers. In many inventory examples, the purchase cost per unit is considered constant. However, when suppliers offer a pricing discount for large-quantity purchases, then the purchase cost becomes variable and is a function of the order quantity. The impact of quantity discounts on inventory policies is discussed later in the chapter.

**order costs** The administrative costs associated with purchasing items.

**inventory carrying costs** The costs associated with storing inventories.

**stockout costs** Encountered when the internal or external demand for items cannot be met.

**purchase cost** The actual cost of the items bought from suppliers.

## INVENTORY RISK AND VALUE

As we have somewhat alluded to already, holding too little inventory increases the risk of a stockout and its associated costs. To reduce this risk, the firm can employ more accurate forecasting techniques and use collaborative planning and forecasting techniques with customers to reduce demand uncertainties and the corresponding need to carry safety stock. Ultimately, managers must compare the cost of carrying safety stock to the cost of stocking out.

On the other hand, carrying more inventory means that more customers will be serviced in a timely fashion, creating happy customers and repeat sales. This is then the value of inventory, and cannot be taken lightly. Too often, it seems, managers become fixated on reducing

**Table 7.3** The Costs of Inventory

Type of Cost	Description
<b>Order cost</b>	The administrative costs associated with purchasing items.
<b>Inventory carrying cost</b>	The costs associated with storing inventories.
<b>Stockout cost</b>	The cost of a lost sale, lost goodwill, or damage to the firm's reputation, as well as lost future sales, and possibly the cost to process a backorder, when no stock is available.
<b>Purchase cost</b>	The actual cost of the items bought from suppliers.

inventory costs as part of a firm-wide cost reduction effort, only to find that stockouts have then increased and customers have started complaining. Today, average retail stockout rates are about 8%, and recent surveys of shoppers indicate that stockouts are the number one shopping annoyance.<sup>6</sup> Firms that can do a good job of managing their inventories—using better forecasts, better communication with customers and suppliers, and better delivery systems—can reduce the cost of inventories without increasing stockouts.

## THE BULLWHIP EFFECT

In a supply chain, one potential costly problem associated with forecasting and the use of safety stock is the **bullwhip effect**. Manufacturers producing goods based on demand forecasts will in some cases add safety stock to their planned production schedules to reduce the risk of stockouts. This, in turn, means additional purchases of parts and assemblies from suppliers. Suppliers then unknowingly create their forecasts based on these inflated sales numbers while also adding their own safety stock to their production schedules. In this way, inventories and order sizes continue to become amplified as one moves further back in the supply chain. This inventory amplification problem can add significant costs to all of a supply chain's members, resulting in more expensive end-items for consumers. Additionally, overstock situations are likely to occur, forcing markdowns to unload slow-moving products, and production slowdowns and smaller purchases to reduce inventories. These activities then increase the risk of stockouts. Better planning, information, and inventory management practices will help to reduce these boom-and-bust cycles of the bullwhip effect.

The costs associated with the bullwhip effect can be significant. These include the costs of idle capacity, excess inventory, stockouts, and inflated purchase prices. Several years ago, office supply retailer Staples admitted carrying extra products in its warehouses to fill in for unexpected lapses in deliveries from its suppliers, or for unexpected demand surges. Additionally, Staples' suppliers carried their own levels of safety stock to be able to respond to Staples' demands, as well as all of the demand from other major office supply retailers. Staples and its suppliers found they were losing millions in extra inventory holding costs and lost sales each year.<sup>7</sup>

In the U.S. oil industry, the volatility of oil prices and hence demand over the past 15 years has induced the bullwhip effect. The demand changes cause reverberations in drilling, production, and capacity, which impact demand and storage of oil and gas equipment, turbines, motors, generators, engine electrical equipment, iron castings, and steel. The bullwhip effect costs the oil industry about \$2 billion per year. When extrapolated to all oil and gas industry purchases, this “bullwhip tax” adds approximately 10% to the cost of every barrel of oil produced. Equipment and component suppliers bear even more of this cost than oil companies.<sup>8</sup>



Watch inventory management on an enormous scale at Amazon

## INDEPENDENT DEMAND INVENTORY MODELS

7.4

Calculate the EOQ and reorder point under various demand and lead time conditions

**Independent demand** refers to the external demand for a firm's finished products. The firm forecasts this demand, and then translates these forecasts into aggregate production plans and purchase plans. If the firm is a retailer, then the independent demand forecasts translate directly into purchase plans. When making purchase plans, the firm must decide *when to order* and *how much to order*, and these and other related inventory management topics are covered in the sections just below.

If the firm is a manufacturer, then the independent demand forecasts are translated internally into all of the parts, assemblies, and materials comprising the finished item. These items are referred to as **dependent demand** items, because their quantities are completely dependent on the quantities of the finished goods produced. For example, if a bicycle manufacturer forecasts an annual bicycle demand of 10,000 units (independent demand), this means it must manufacture 20,000 bicycle rims and purchase 10,000 bicycle seats (dependent

**bullwhip effect** Forecasts of demand combined with additions of safety stock that tend to amplify purchases from suppliers. As suppliers then make forecasts and also add safety stock, inventories become still more amplified as we move back up the supply chain. This inventory amplification problem can add significant costs to the supply chain.

**independent demand** The external demand for a firm's finished products.

**dependent demand** Parts that are required to build end-items and are *dependent* on the external demand of the finished product.

demand items). Managing this transformation process and the many dependent demand items are discussed in Chapter 11.

## DECIDING HOW MUCH AND WHEN TO ORDER

Management's decision regarding *how many* units to order at one time is based on a knowledge of **total annual inventory costs** (which are the sum of the annual inventory carrying costs, order costs, stockout costs, and purchase costs). The general idea is to find an order quantity that will minimize total annual inventory costs. The decision of *when* to order is based on knowledge of how long orders take to arrive once an order has been placed (the **order lead time**), and how many units are likely to be demanded during the order lead time period. One very basic model in use that provides information for these decisions is the economic order quantity, or fixed order quantity model. The second basic inventory model is the fixed time period model. These are reviewed next.

## THE ECONOMIC ORDER QUANTITY MODEL

The basic **economic order quantity** (EOQ) model derives the order quantity that will minimize the sum of the annual inventory holding cost and the annual order cost. The model uses the following assumptions:

- Daily demand is constant.
- Each purchase order arrives in a single delivery at known delivery date (there are no stockouts).
- The purchase order lead time (the number of days from order until receipt) is known and constant.
- Order costs are known and constant.
- Inventory carrying costs per unit are known and constant.
- There are no purchase quantity discounts (purchase price is constant).

Using these assumptions, it is easy to see that the firm would know *exactly* when its stock levels would be depleted, and know with certainty that a purchasing order would be delivered *exactly* when it is expected. Also, since there are no purchase quantity discounts allowed with the basic EOQ model, then the annual purchase cost will remain constant regardless of the quantity ordered each time. Thus, the relevant total annual inventory cost reduces to the sum of the annual inventory carrying cost and the annual order cost. While these assumptions are obviously unrealistic, many firms still use the EOQ calculation when ordering from suppliers, due to its simplicity and ability to result in an order quantity that comes fairly close to minimizing inventory costs, even in real-world situations. Figure 7.1 shows the important EOQ model information.

As shown in Figure 7.1, the constant economic order quantity,  $Q$ , arrives every  $Q/d$  days (where  $d$  is the constant daily demand), and is depleted at the constant daily demand rate. The order lead time is constant and equal to  $L$ . The **reorder point**, or ROP, is the inventory on-hand needed to satisfy demand during the order lead time period, and is equal to  $d \times L$ . No safety stock is required, since the new order is timed to arrive exactly when the inventory on-hand reaches zero. Finally, the average inventory level is  $Q/2$ , which is the average of the maximum inventory,  $Q$ , and the minimum inventory, zero. With this information, it is then possible to calculate the annual order cost,  $O$ , which is:

$$O = \frac{D}{Q}S,$$

where  $D$  = annual demand (units/year),

$Q$  = purchase order quantity (units), and

$S$  = cost of one purchase order (\$).

Note also that  $D/Q$  = the number of orders per year, and that  $Q/d$  = the number of days between orders.

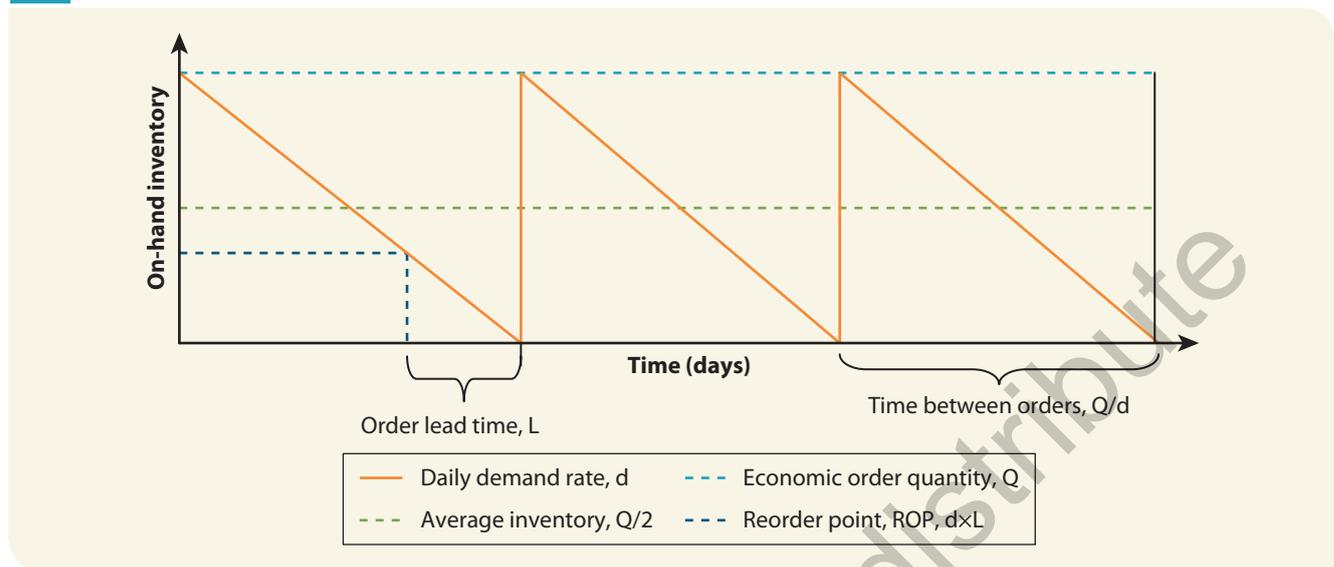
**total annual inventory costs** The sum of the annual inventory carrying costs, order costs, stockout costs, and purchase costs.

**order lead time** The time from order receipt to delivery to the customer.

**economic order quantity** The order quantity that will minimize the sum of the annual inventory holding cost and the annual order cost.

**reorder point** The inventory on-hand needed to satisfy demand during the order lead time period.

Figure 7.1 The EOQ Model



The annual inventory carrying cost,  $I$ , is:

$$I = \frac{Q}{2} iC,$$

where  $Q$  = purchase order quantity (units),

$I$  = carrying cost rate per unit per year (%/year), and

$C$  = purchase cost of one unit (\$/unit).

The relevant total annual inventory cost for the EOQ model is then  $O + I$ . Figure 7.2 shows the relationship between the annual order cost, the annual inventory carrying cost, and the total annual inventory cost.

As shown in Figure 7.2, the minimum total annual inventory cost and the EOQ are found at the point where the annual order cost equals the annual inventory carrying cost. Thus, the expression for the EOQ can be found by setting the annual order cost equal to the annual inventory carrying cost, as follows:

$$\frac{D}{Q}S = \frac{Q}{2}iC, \text{ or}$$

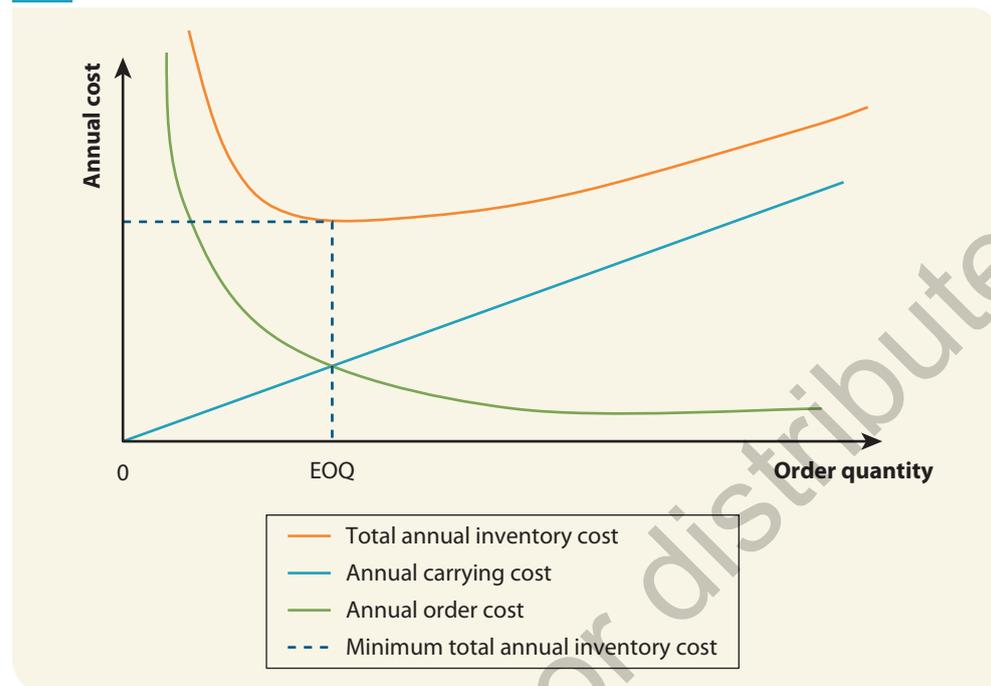
$$Q^2 = \frac{2SD}{iC}, \text{ or}$$

$$EOQ = \sqrt{\frac{2SD}{iC}}.$$

Note also the flatness of the total inventory cost curve around the minimum point in Figure 7.2. This characteristic is what allows managers to use the EOQ even though demand, order lead time, order cost, and carrying cost may not necessarily be constant. Due to this flatness of the total inventory cost curve around the minimum point, the EOQ model is said to be a **robust model**. Example 7.1 provides a general inventory problem for a company such as a retailer, illustrating all of the relevant inventory equations.

Knowing how much to order from suppliers and when to order is certainly important, since having too much inventory is costly from a carrying cost perspective, and having too

**robust model** Refers to the flatness of the total inventory cost curve, which means the EOQ model can be used in a variety of situations.

**Figure 7.2** Inventory Costs and the EOQ

little results in stockouts and lost sales. It is also important from a supply chain management perspective, since being unable to supply a key business customer can result in stockouts for them and potentially a plant shutdown. Furthermore, ordering in an unpredictable or random fashion from key suppliers can worsen the bullwhip effect. Recall that the order fulfillment process is considered one of the key supply chain processes described in Chapter 1. The following segment discusses several extensions of the EOQ model.

**Example 7.1**  
Solving a Standard  
Inventory Problem at a  
Retailer



**Solving a Standard Inventory Problem at a Retailer**

The Hayley-Girl Beret Shop would like to determine optimal inventory policies for ordering berets from its beret supplier. The owner assumes that annual beret demand is a constant 5,000 berets. The order cost is \$100, the carrying cost rate is 30% per year, the purchase cost is \$40 per beret, and the order lead time is seven days. The optimal order quantity in whole units is:

$$EOQ = \sqrt{\frac{2SD}{iC}} = \sqrt{\frac{2(100)(5000)}{.3(40)}} = \sqrt{83,333.3} = 289 \text{ units}$$

The annual order cost is:

$$O = \frac{D}{Q} S = \frac{5000}{289} (100) = \$1,734.10.$$

The annual inventory carrying cost is:

$$I = \frac{Q}{2} iC = \frac{289}{2} .3(40) = \$1,734.00.$$

Note here that O and I are not equal, because the EOQ has been rounded off to a whole number of units, as would be the case in a real situation involving an order of hats. The relevant total annual inventory cost is:

$$T = O + I = \$1730.10 + \$1734 = \$3464.10.$$

This does not include the annual purchase cost of \$200,000, which remains constant regardless of the order policy. The number of orders the Hayley-Girl Beret Shop will make per year are:

$$n = \frac{D}{EOQ} = \frac{5000}{289} \approx 17 \text{ orders.}$$

The number of days between orders is:

$$t = \frac{EOQ}{d} = \frac{289}{5000/365} \approx 21 \text{ days}$$

The reorder point is:

$$ROP = d \times L = \frac{500}{365}(7) \approx 96 \text{ units.}$$

So, the optimal order policy is for the owner to order 289 berets whenever the on-hand inventory reaches 96 berets. Seven days later the order will arrive, just as the stock of berets is running out. The owner should check on-hand inventory and potentially order every 21 days.

A spreadsheet can also be used to calculate the statistics as shown below:

	A	B
1	Values	Stats
2	5000	288.68
3	100	1732.05
4	0.30	1732.05
5	40	3464.10
6	7	17.32
7		21.07
8		95.89

B2: =SQRT(2\*A2\*A3/(A4\*A5))

B3: =(A2\*A3)/B2

B4: =(B2\*A4\*A5)/2

B5: =B3+B4

B6: =A2/B2

B7: =B2/(A2/365)

B8: =(A2/365)\*A7

## EXTENSIONS OF THE EOQ MODEL

### Allowing Purchase Price to Vary

One of the common extensions of the EOQ is when the purchase price is allowed to vary—for instance, when quantity discounts are offered by a supplier. In this case, the **quantity discount model** can be used, and is illustrated in Figure 7.3. The supplier may offer several discounted prices, depending on the purchase quantity, resulting in several total cost curves, shown in Figure 7.3. Operations managers must then consider each of the purchase prices, along with the impact on total annual costs when determining the optimal order policy. With a varying purchase price, the relevant equation for the total annual inventory cost becomes:

$$T = O + I + P,$$

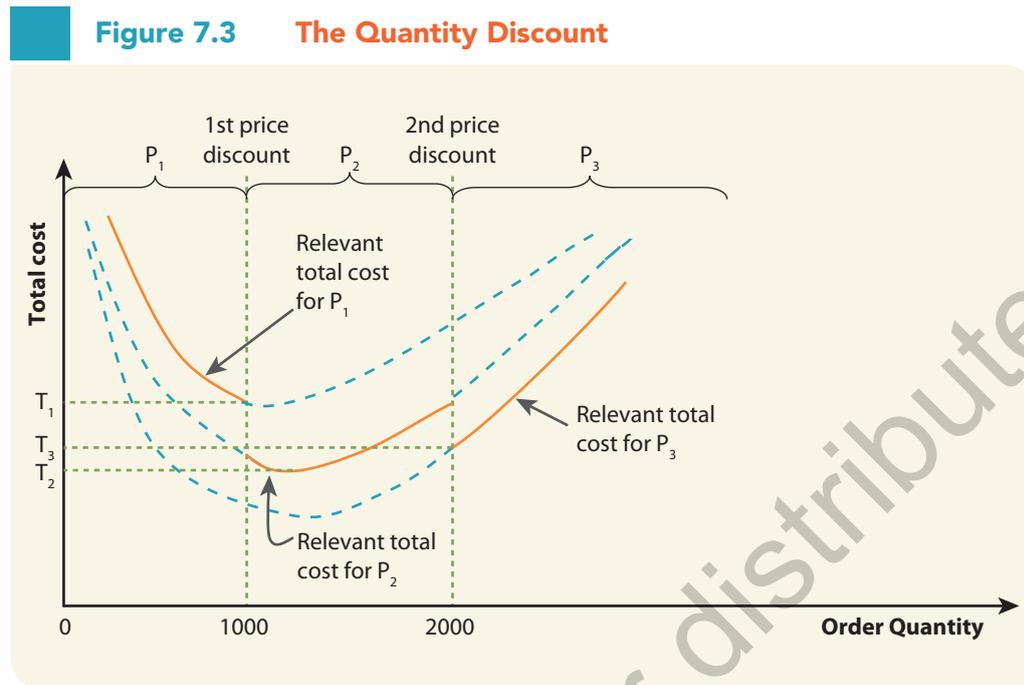
where  $O$  = annual order cost,

$I$  = annual inventory carrying cost, and

$P$  = annual purchase cost.

#### quantity discount model

An extension of the EOQ to be used when the purchase price is allowed to vary—for instance, when quantity discounts are offered by a supplier.



A final note here regarding discounted pricing might be warranted. Firms may opt to purchase fewer items and forgo a quantity discount to reduce obsolescence costs and theft, or perhaps because they don't want to use precious storage space. Also, suppliers today are moving toward greater use of "everyday low pricing" to avoid inventory buildups and sell-offs, which also reduces the bullwhip effect. Recently, retailer J. C. Penney moved to everyday low pricing in part to reduce expenditures on promotions—it expects to save about \$75 million per year on promotions with its "fair and square" pricing approach.

As shown in Figure 7.3, two discounts are offered, resulting in three potential purchase prices— $P_1$  is the purchase price if fewer than 1,000 units are purchased;  $P_2$  corresponds to a purchase quantity between 1,000 and 1,999 units; and  $P_3$  is the price paid when ordering 2,000 or more units at one time. Thus, three total cost curves are shown, with the solid red lines corresponding to the actual total annual inventory costs when various quantities are ordered. Note that  $T_1$ ,  $T_2$ , and  $T_3$  represent the minimum total annual inventory costs associated with each of the three purchase prices. Also note that if more than 2,000 units are ordered, the corresponding EOQ for that price cannot be used, since that quantity would fall at the minimum point of the curve, which is between 1,000 and 2,000. Instead, the minimum total inventory cost when paying  $P_3$  would fall at the minimum quantity to get that discount.

Example 7.2 illustrates the determination of the optimal order quantity, using several purchase quantity discounts. Note that in this example, the optimal purchase quantity was not one of the calculated EOQs. Instead, the buyer would prefer purchasing 500 units at a time, in order to pay \$65 per unit. In this case, the savings in annual purchase cost more than offset the additional carrying cost when using the discounted price of \$65 per unit and ordering 500 units at a time.

**probabilistic demand reorder point model** When variable demand exists, this model assumes the purchase lead time to be constant; however, the time between orders would vary. The model says to order the EOQ whenever the inventory on-hand reaches the reorder point level.

### ALLOWING DEMAND TO VARY

If demand is allowed to vary, then the possibility of a stockout exists, and inventory policies must include the use of safety stocks. Demand in this case must be specified using a probability distribution. Managers can still calculate an EOQ using the average annual demand, and this quantity can still be ordered; however, the reorder point, or ROP, will have to include safety stock. Figure 7.4 presents the **probabilistic demand reorder point model**,

The Ceejay Software Company purchasing agent needs to determine the lowest total annual cost order quantity for a particular high-selling software product. The manufacturer is offering several pricing incentives to encourage bulk-buying. The pricing alternatives are:

- \$75 per unit for 1–499 units purchased,
- \$65 per unit for 500–999 units purchased, and
- \$60 per unit for 1,000 or more units purchased.

Ceejay's average order cost is \$75 per order, the forecasted annual demand for the product is 850 units, and the inventory carrying cost rate is 35% per year. The Ceejay purchasing agent first calculates the EOQ for each of the three purchase prices:

$$EOQ_1 = \sqrt{\frac{2(850)(75)}{0.35(75)}} = 70 \text{ units}$$

$$EOQ_2 = \sqrt{\frac{2(850)(75)}{0.35(65)}} = 75 \text{ units}$$

$$EOQ_3 = \sqrt{\frac{2(850)(75)}{0.35(60)}} = 78 \text{ units}$$

Since only  $EOQ_1$  is a valid order quantity (both of the other EOQs are below the minimum to get a discount), the purchasing agent must use  $EOQ_1$  to calculate  $T_1$ , the total annual inventory cost for the \$75 per unit alternative, and then use the minimum order quantities when calculating the other two annual inventory costs. The total annual inventory costs are then:

$$T_1 = O_1 + I_1 + P_1 = \frac{850(75)}{70} + \frac{70(0.35)(75)}{2} + 850(75) = \$911 + \$919 + \$63,750 = \$65,580,$$

$$T_2 = O_2 + I_2 + P_2 = \frac{850(75)}{500} + \frac{500(0.35)(65)}{2} + 850(65) = \$128 + \$5,688 + \$55,250 = \$61,066, \text{ and}$$

$$T_3 = O_3 + I_3 + P_3 = \frac{850(75)}{1000} + \frac{1000(0.35)(60)}{2} + 850(60) = \$64 + \$10,500 + \$51,000 = \$61,564.$$

So it is seen that the lowest cost inventory policy is to purchase 500 units each order, and the purchase price will be \$65 per unit, resulting in a total annual inventory cost of \$61,066.

This problem can also be solved using a spreadsheet:

	A	B	C	D
1	Data	EOQ Calcs	Order Sizes	Total Inventory Costs
2	75	69.69	70	65579.46
3	65	74.86	500	61065
4	60	77.92	1000	61563.75
5	850			
6	75			
7	0.35			

B2: = SQRT(2\*A5\* A6/(A7\*A2))

D3: = (A5\*A6/C3)+ (C3\*A7\*A3/2)+ (A5\*A3)

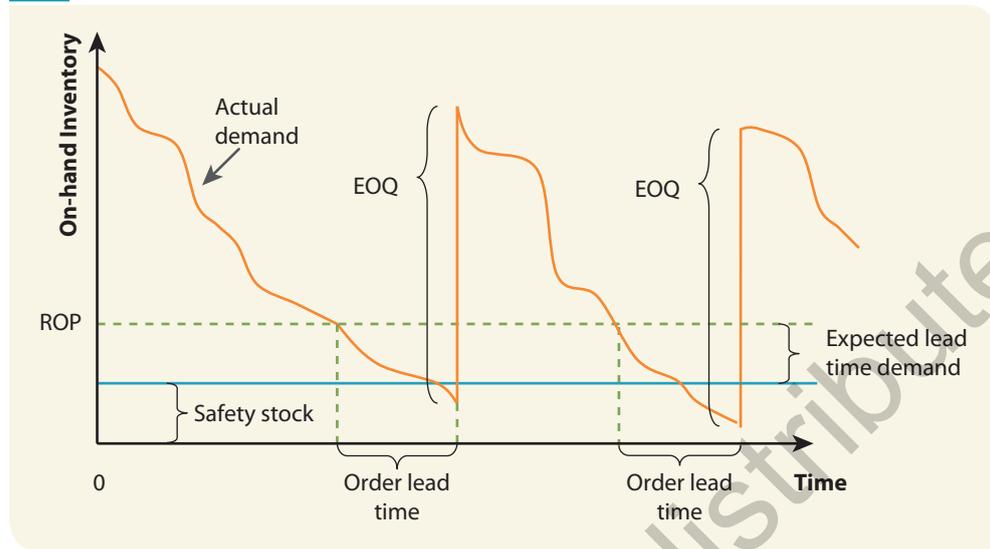


**Example 7.2**  
Finding the Optimal Order Quantity When Quantity Discounts Are Offered



where a variable demand situation is illustrated. This model still assumes the purchase order lead time to be constant; however, the time between orders would vary, since orders are made whenever the inventory on-hand reaches the reorder point level. The order policy for this situation thus becomes: *order the EOQ whenever the reorder point is reached.*

**Figure 7.4** The Probabilistic Demand Reorder Point Model



The probabilistic demand ROP is determined by the following:

$$ROP = \text{lead time demand} + \text{safety stock} = \bar{d}(L) + Z(\sigma L)$$

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

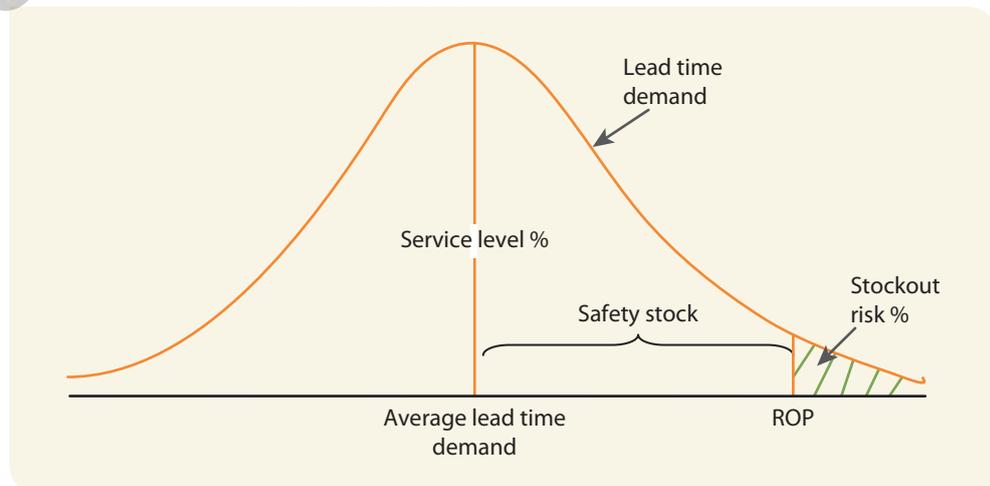
L = purchase order lead time,

Z = number of standard deviations required for a desired service level, and

$\sigma L$  = standard deviation of lead time demand.

Note that this formulation for the ROP is somewhat different than the ROP used with the classical EOQ model. In the classical model, the ROP is set equal to the lead time demand. Now, with variable demand, a safety stock component must be added to the ROP, to help ensure that the firm will not stockout while waiting on an order to be delivered from the supplier. The following segment describes how to find Z.

**Figure 7.5** Variable Demand, the ROP, Safety Stock, and the Service Level



### Determining Z

The level of safety stock used depends on the desired **service level**. Service level is generally defined as the percent of time the firm does not want to stockout during the order lead time period, or the area under the demand distribution that is covered by, or to the left of, the ROP, as shown in Figure 7.5. The value for Z is determined based on this desired service level. Assuming a normal distribution of lead time demand, Table 7.4 can be used to find the appropriate Z for a desired service level. Note that if the ROP from the classical EOQ was used with varying demand, the corresponding service level would only be 50%, and the firm would expect to become stocked out 50% of the time, while waiting on an order to be delivered. Example 7.3 provides the calculations for the probabilistic demand ROP.

John and Janie's Hawg Heaven store sells Harley-Davidson accessories, and it wants to calculate an appropriate ROP for many of its items. Its Harley T-shirts are one such example. The annual forecast for these T-shirts is 4,500 shirts. The lead time for T-shirt purchases is always six days. The daily demand for Harley T-shirts varies, and John and Janie's has calculated the standard deviation of lead time demand to be approximately 15 shirts. The store desires to have a 95% service level. Assuming it is open 300 days per year, then:

$$\text{ROP} = \bar{d}(L) + Z\sigma = \frac{4500}{300}(6) + 1.64(15) = 90 + 24.6 = 115 \text{ shirts.}$$

The Z-value is found using Table 7.4, and searching for an area under the curve as close as possible to 0.95 (the service level). The Z is 1.64, and thus the safety stock corresponding to a 95% service level is 25 units. The store's order policy should then be to order the EOQ whenever the stock of T-shirts falls to 115. It would expect that 5% of the time, the store would be stocked out of T-shirts when the supplier arrives.

### Example 7.3 Calculating the Probabilistic Demand ROP

### Allowing Both Demand and Lead Time to Vary

In an even more realistic model, both demand and purchase order lead times are assumed to vary and be normally distributed. Combining demand variability with lead time variability greatly increases the variance of the joint distribution along with the safety stock needed to ensure a given service level. The new ROP will need to include this safety stock increase. The expected demand during the order lead time is then the average daily demand multiplied by the average lead time, and the variance of lead time demand is the sum of the variances of the daily demand and the lead time. The standard deviation of the lead time demand is then:<sup>9</sup>

$$\sigma_{dLT} = \sqrt{\bar{L}\sigma_d^2 + \bar{d}^2\sigma_L^2}$$

where  $\bar{L}$  = average order lead time,

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

$\sigma_d^2$  = variance of daily demand, and

$\sigma_L^2$  = variance of order lead time.

The **probabilistic demand and lead time reorder point model** can then be expressed as:

$$\text{ROP} = \bar{d}(\bar{L}) + Z\sqrt{\bar{L}\sigma_d^2 + \bar{d}^2\sigma_L^2}.$$

The Z-value in the ROP calculation is again found in Table 7.4, given a desired service level. Example 7.4 provides a calculation of the probabilistic demand and lead time ROP.

**service level** The percentage of time the firm does not want to stockout during the order lead time period, or the area under the demand distribution that is covered by, or to the left of, the ROP.

**probabilistic demand and lead time reorder point model** When variable demand and variable lead time exist, the model says to order the EOQ whenever the inventory on-hand reaches the reorder point level.

**Table 7.4** Z-Values for Areas Under the Normal Curve

Z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.5	.69146	.69497	.69847	.70194	.70540	.70884	.71226	.71566	.71904	.72240
.6	.72575	.72907	.73237	.73536	.73891	.74215	.74537	.74857	.75175	.75490
.7	.75804	.76115	.76424	.76730	.77035	.77337	.77637	.77935	.78230	.78524
.8	.78814	.79103	.79389	.79673	.79955	.80234	.80511	.80785	.81057	.81327
.9	.81594	.81859	.82121	.82381	.82639	.82894	.83147	.83398	.83646	.83891
1.0	.84134	.84375	.84614	.84849	.85083	.85314	.85543	.85769	.85993	.86241
1.1	.86433	.86650	.86864	.87076	.87286	.87493	.87698	.87900	.88100	.88298
1.2	.88493	.88686	.88877	.89065	.89251	.89435	.89617	.89796	.89973	.90147
1.3	.90320	.90490	.90658	.90824	.90988	.91149	.91309	.91466	.91621	.91774
1.4	.91924	.92073	.92220	.92364	.92507	.92647	.92785	.92922	.93056	.93189
1.5	.93319	.93448	.93574	.93699	.93822	.93943	.94062	.94179	.94295	.94408
1.6	.94520	.94630	.94738	.94845	.94950	.95053	.95154	.95254	.95352	.95449
1.7	.95543	.95637	.95728	.95818	.95907	.95994	.96080	.96164	.96246	.96327
1.8	.96407	.96485	.96562	.96638	.96712	.96784	.96856	.96926	.96995	.97062
1.9	.97128	.97193	.97257	.97320	.97381	.97441	.97500	.97558	.97615	.97670
2.0	.97725	.97784	.97831	.97882	.97932	.97982	.98030	.98077	.98124	.98169
2.1	.98214	.98257	.98300	.98341	.98382	.98422	.98461	.98500	.98537	.98574
2.2	.98610	.98645	.98679	.98713	.98745	.98778	.98809	.98840	.98870	.98899
2.3	.98928	.98956	.98983	.99010	.99036	.99061	.99086	.99111	.99134	.99158
2.4	.99180	.99202	.99224	.99245	.99266	.99286	.99305	.99324	.99343	.99361
2.5	.99379	.99396	.99413	.99430	.99446	.99461	.99477	.99492	.99506	.99520
2.6	.99534	.99547	.99560	.99573	.99585	.99598	.99606	.99621	.99632	.99643
2.7	.99653	.99664	.99674	.99683	.99693	.99702	.99711	.99720	.99728	.99736
2.8	.99744	.99752	.99760	.99767	.99774	.99781	.99788	.99795	.99801	.99807
2.9	.99813	.99819	.99825	.99831	.99836	.99841	.99846	.99851	.99856	.99861
3.0	.99865	.99869	.99874	.99878	.99882	.99886	.99889	.99893	.99896	.99900

In all of the models discussed so far, the order quantity has been constant and equal to the EOQ. Even though the EOQ was derived assuming constant demand, constant lead time, constant pricing, and the other assumptions listed earlier, the EOQ can nevertheless be used in more real-world situations as illustrated above. In these realistic cases, the order policy has been to order the EOQ whenever the reorder point is reached. This assumes that the inventory manager is continuously tracking inventory levels, using, for example, bar codes on units of product and scanners linked to computers, which keep a running tally of inventory. This may not always be feasible. Let's now explore the periodic review model.

The Jay and Stella T-Shirt Depot desires to use an ROP for the various T-shirts it sells. The purchase order lead time varies, with an average of six days and a standard deviation of two days. The daily demand also varies, with an average of 15 shirts per day and a standard deviation of 3 shirts per day. It would like to maintain a 95% service level. The corresponding Z-value is 1.64, and the ROP is:

$$\begin{aligned} \text{ROP} &= \bar{d}(\bar{L}) + Z\sqrt{\bar{L}\sigma_d^2 + \bar{d}^2\sigma_L^2} \\ &= 15(6) + 1.64\sqrt{6(3)^2 + (15)^2(2)^2} = 90 + 1.64(30.89) \approx 141 \text{ shirts} \end{aligned}$$

The safety stock for this situation is 51 shirts, and the order policy is to order the EOQ whenever the stock level gets down to 141 shirts.



### Example 7.4 Calculating the Probabilistic Demand and Lead Time ROP



## THE PERIODIC REVIEW MODEL

In some cases, it is more practical to order variable quantities at some fixed time interval. For instance, a supplier representative might visit a retailer on a weekly or monthly basis, count inventories of the various products the supplier sells, then order a quantity large enough to satisfy demand until the next visit by the sales representative. For relatively stable demand, low-profit items, or cases when stockout costs are fairly low, it may make sense to forgo the costs of bar codes, scanners, and computers to continually track inventories so as to identify the ROP.

Consider, for example, a vending machine operator. She visits the machines weekly and fills each item to some predetermined level based on demand histories, so that inventories will last until the following week. This is essentially describing the **periodic review model**. Assuming variable demand, this model uses a variable order quantity at fixed reorder periods (whereas the reorder point model uses a fixed order quantity at variable reorder periods). Additionally, safety stocks for the periodic review model are higher when compared to the reorder point model. When using the reorder point model, stock levels are monitored continuously, and an order is placed when the ROP is reached. Thus, the only time a stockout can occur is during the order lead time period. With the periodic review model, inventory is counted only at the specified review period, when an order is then placed. If demand were to be unexpectedly large soon after the order was placed, then a stockout could occur and go unnoticed until the next review period. Thus, a stockout could occur during the review period or the order lead time period. Consequently, more safety stock must be utilized for the periodic review model.

### Deriving the Periodic Review Model Calculations

Figure 7.6 illustrates the periodic review model using a review period of P, an order lead time of L, varying order quantities of Q, an order-up-to or target quantity T, and probabilistic demand. Note in the figure that inventory is depleted, creating a stockout prior to the arrival of Q<sub>2</sub>.

#### The Review Period

The **optimal review period** is found by using the average daily demand and the EOQ, then calculating P as:

$$P = \frac{\text{EOQ}}{\bar{d}}$$

Where P = review period (in days), and

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

Recall this equation was used in the EOQ section to calculate days between orders. A review period of this magnitude should result in low inventory monitoring and stockout costs (note here that the EOQ is still being used, which further supports the importance of the EOQ).

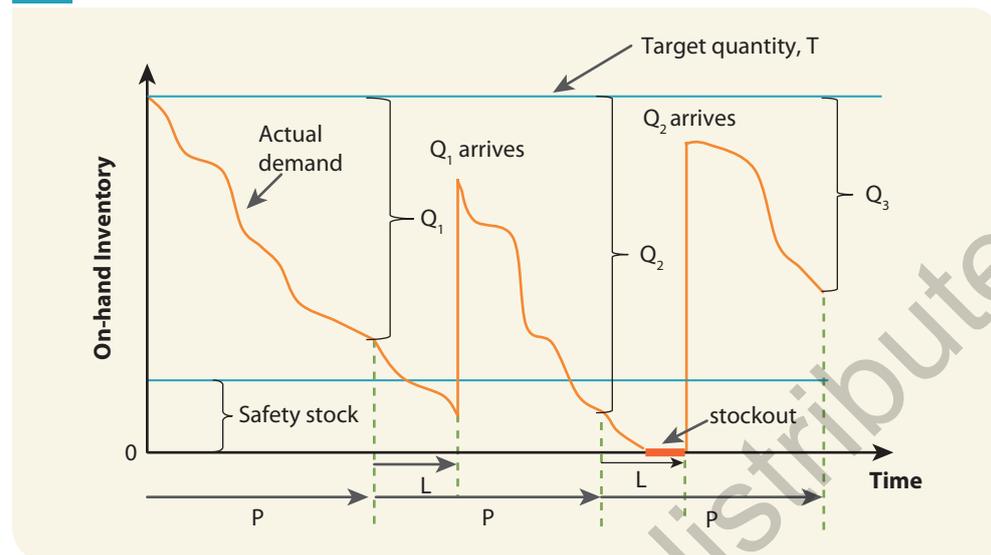
#### periodic review model

Assuming variable demand, this model uses a variable order quantity at fixed reorder periods. Requires higher safety stock levels than the reorder point models.

#### optimal review period

Used for the periodic review model. It is found by dividing the EOQ by the average daily demand.

**Figure 7.6 The Periodic Review Model**



### Safety Stock

Using the periodic review model, inventory is counted every  $P$  days, an order  $Q_i$  is placed, and the order arrives in  $L$  days. Since a stockout can occur at any time during the  $P+L$  period, the safety stock required is:

$$\text{Safety stock} = Z(\sigma_{P+L})$$

where  $Z$  = number of standard deviations required for a desired service level,

$P$  = review period,

$L$  = purchase order lead time, and

$\sigma_{P+L}$  = standard deviation of (fixed review period + lead time) demand.

Normally, the standard deviation of the daily demand distribution is readily available. This can be used to generate  $\sigma_{P+L}$ , by assuming that the variance of the demand during the  $P+L$  days of time will be the sum of the variances of the  $P+L$  identical and independent daily distributions of demand, or:

$$\sigma_1^2 + \sigma_1^2 + \sigma_1^2 + \dots = (P+L) \sigma_1^2$$

where  $\sigma_1^2$  = variance of daily demand. Finally, the standard deviation of demand during  $P+L$  days of time is:

$$\sigma_{P+L} \sqrt{(P+L) \sigma_1^2} = \sigma_1$$

### Target Quantity

The inventory manager must determine an order-up-to or **target inventory level** using the average daily demand and its standard deviation, so that a stockout situation can be avoided most of the time. Using the above-defined variables, this target quantity can be expressed as:

$$T = \bar{d} (P+L) + Z(\sigma_{P+L})$$

### Order Quantity

The order quantity  $Q_i$ , varies based on the inventory on-hand when each review period occurs. Thus, to determine the order quantity, the current inventory level is counted and subtracted from the target quantity  $T$ :

**target inventory level** The order-up-to level when using the periodic review model.

$$Q_i = T - K_i$$

Where  $Q_i$  = order quantity in review period  $i$ , and

$K_i$  = inventory on-hand in review period  $i$ .

Example 7.5 illustrates the use of the periodic review model.

The Budget T-Shirt store wants to use a periodic review system for its basic T-shirt. The shirt has an annual demand forecast of 4,500 shirts. Its order cost is \$50, and its inventory carrying cost is 15% per dollar per year. The cost of each shirt is \$10. The purchase order lead time is six days and the average daily demand is 15 shirts, with a daily standard deviation of 3 shirts. Budget T-Shirt would like to maintain a 95% service level (the corresponding Z-value is 1.64, from Table 7.4).

The EOQ =  $\sqrt{\frac{2SD}{iC}} = \sqrt{\frac{2(50)(4500)}{.15(10)}} = 548$ ;  $P = \frac{EOQ}{d} = \frac{548}{15} \approx 37$  days. Its target inventory level is:

$$T = \bar{d}(P+L) + Z(\sigma_{P+L}) = 15(43) + 1.64\sqrt{43}(3) = 645 + 32.3 \approx 677$$

Therefore, Budget T-Shirt's periodic review policy should be to count its basic T-shirts every 37 days, then order  $(677 - K)$  shirts. Six days later, its order will arrive.

### Example 7.5 Using the Periodic Review Model

## ABC INVENTORY CLASSIFICATION

The **ABC inventory classification** approach is used to help companies manage their independent demand inventories. The idea is to pay closer attention to items accounting for a larger percentage of the firm's annual spend. Typically, the Class A items (the most important) represent about 20% of inventory SKUs and account for perhaps 80% of the firm's annual spend. These items should be monitored closely (counted often) and have adequate levels of safety stock, to ensure the highest service levels. Class B items account for

**ABC inventory classification** An approach used to help companies manage their independent demand inventories. The idea is to pay closer attention to items accounting for a larger percentage of the firm's annual spend. The Class A items (the most important) represent about 20% of inventory SKUs and account for perhaps 80% of the firm's annual spend.

## Managing Inventories Is Like ABC at Metso



Brazilian energy company Petrobras recently agreed to let Finland-based valve manufacturer Metso manage Petrobras's valve and spare parts inventories. The deal reflects a growing interest in reducing costs, and inventory represents a large source of tied-up capital for many companies. Since starting its service, Metso has secured about 100 clients.

Metso produces and then stores the inventories and can typically reduce average inventory levels for its clients by about 50% within a year. Customers pay a monthly service fee and a capital fee based on the size of the inventories. Metso holds the inventories at its regional facilities, and delivers on demand at pre-agreed prices.

The agreement allows for different delivery times, based on the criticality of the part. The classifications are Class A—same-day delivery critical items; Class B—next-day delivery; Class C—four-to five-day delivery; and Class D—factory delivery, for remaining parts.

All projects start with an analysis of the client's valve assemblies to establish adequate inventories for every valve in the facility. In many cases, even though a firm may have a large valve inventory at the start of a project, it might stock out of 40–50% of the valves used, particularly if unexpected events occur. It also might find many older valve models in inventory. Over time, Metso replaces these with the latest models. Typically, after the first year, valve inventories are down significantly.<sup>10</sup>

## SERVICE SPOTLIGHT

**Example 7.6**  
**Using the ABC**  
**Inventory**  
**Classification Method**



Blake's Music Emporium had a number of inventory items, and the owner wanted to make sure he had the right inventory policies in place for each item. The 10 items shown below are a representative group of stock items.

Item SKU	Cost/Unit (\$)	Forecasted Annual Demand	Projected Annual Spend (\$)	Percent of Spend (Class)
000325	26.45	3750	99,187.50	33.1 (A)
001026	12.40	2500	31,000.00	10.3 (B)
000977	4.35	6240	27,144.00	9.1 (B)
000265	2.79	260	725.40	0.2 (C)
001236	145.99	150	21,898.50	7.3 (B)
000635	345.00	300	103,500.00	34.5 (A)
000079	87.35	30	2,620.50	0.9 (C)
001166	146.80	50	7,340.00	2.4 (C)
000439	55.20	100	5,520.00	1.8 (C)
000237	37.16	25	929.00	0.3 (C)
			Total: \$299,864.90	

Based on these findings for the upcoming year, Blake classified items 000325 and 000635 as A items; 001026, 000977, and 001236 as B items; and 000265, 000079, 001166, 000439, and 000237 as C items. Blake then decided to increase the safety stocks of the A items and count them more frequently, while doing away with the safety stock of the C items.

The ABC analysis shown above can also be performed using a spreadsheet, as shown below:

	A	B	C	D
1	<b>Cost/Unit</b>	<b>Annual Demand</b>	<b>Annual Spend</b>	<b>% of Spend</b>
2	26.45	3750	99187.5	33.1
3	12.4	2500	31000.0	10.3
4	4.35	6240	27144.0	9.1
5	2.79	260	725.4	0.2
6	145.99	150	21898.5	7.3
7	345	300	103500.0	34.5
8	87.35	30	2620.5	0.9
9	146.8	50	7340.0	2.4
10	55.2	100	5520.0	1.8
11	37.16	25	929.0	0.3
12		Total	299864.9	

C2: = A2\*B2

D2: = C2/299864.9

D9: = C9/299864.9

C11: = A11\*B11

C12: = SUM(C2:C11)



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approximately 15% of annual spend and represent about 30% of inventory SKUs. The B items are moderately important and can be monitored less closely, with lower levels of safety stock. Class C items are the least important to the firm, representing about 50% of the inventory SKUs while accounting for only about 5% of spend. Service levels can be low for these items, and this group represents an area where large savings in inventory carrying costs can be realized. Class C items should only be checked periodically, and safety stock levels should be very low or zero. Many companies today use the ABC method to reduce safety stock inventories and to get rid of slow-moving items. The nearby Service Spotlight shows how an ABC system is used by Metso to manage inventories.

Example 7.6 illustrates the ABC inventory classification approach. Notice that the inventory SKU and spend breakdowns do not exactly represent the percentages mentioned above. The percentages are only used as guidelines. While this is a managerial decision, it should be fairly obvious in which category each inventory item is placed.

## ORDER QUANTITIES AND SAFETY STOCK AMONG SUPPLY CHAIN PARTNERS

In the discussions above, the general objective was to minimize the focal firm's total annual inventory costs for a desired service level, which led to the use of the EOQ, the periodic order quantity, and several reorder point formulations, depending on assumptions regarding demand, review period, and order lead time. Safety stock was held to help the firm avoid stockouts when demand was larger than expected, when order lead times were longer than expected, and when the inventory review was not continuous. Each firm acted independently to minimize its annual inventory costs.

When supply chain partners such as the firm's key suppliers and customers are considered, though, the inventory objectives and strategies may be altered somewhat. Safety stock levels tend to be significantly less, since supply chain partners use collaborative planning, forecasting, and replenishment (as discussed earlier, in Chapter 6). Order lead times and demand quantities tend to be more predictable and reliable, which reduces the need for safety stock. In essence, the general idea behind actively managed supply chains is that cooperation, information sharing, inventory visibility, and collaborative planning cause demand and lead time to behave closer to the assumptions used with the classical EOQ model. The final topic of this chapter is tracking inventory management performance, discussed next.

## MEASURING INVENTORY MANAGEMENT PERFORMANCE

7.5

Discuss the importance of inventory management performance measures

No discussion of inventory management would be complete without considering the tracking of **inventory management performance**. Given the earlier general presentation of operations performance in Chapter 2 and the examination of inventories in this chapter, the performance dilemma associated with inventories should be obvious—the presence of inventories helps to create good customer service, but inventory carrying costs can account for a very large portion of a firm's costs. This balancing act is one that successful firms have mastered—in a recent survey conducted by APQC, a nonprofit, member-based organization specializing in performance analytics and best practices, firms on average spend about 10% of the value of their inventories on carrying costs each year. Interestingly, the most profitable firms spend only 7%, while the least profitable firms spend about 16.5%. These excess carrying costs can amount to millions of dollars each year in lost profits.<sup>11</sup>

Inventory performance measures should assess performance both inside and outside the firm. The dual objectives of maximizing customer service while minimizing inventory costs require close and frequent attention to the policies and tools used when purchasing, processing, and distributing goods and services. Stockouts and excessive carrying costs can become

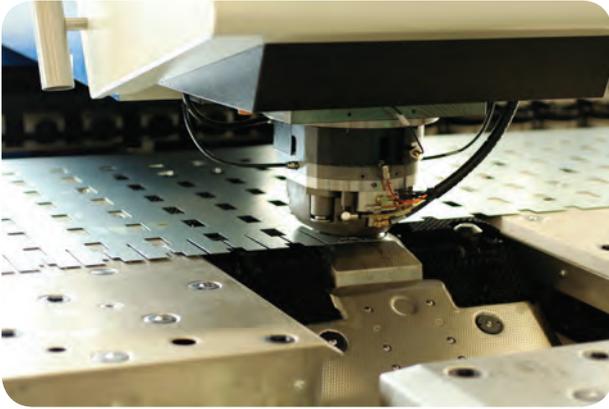


See how performance measures can sometimes cause bad things to occur

**inventory management performance** Measures of how well companies are creating good customer service while keeping inventories low.

## MANUFACTURING SPOTLIGHT

### Designing a Performance Measurement System at Talan



While a number of fairly common industry performance measures can be found in many successful companies, no standard set of measure exists that is right for every company. Each company must consider what it is looking for, and what it can track that can help it achieve its objectives.

Ohio-based metal stamping firm Talan Products, for example, began forming a set of performance measures when managers and key personnel brainstormed questions like, “What do we need to get better at?” and included discussions of each measure prior to the team making a final selection. In all, it took Talan Products about 12 hours over several days to arrive at a set of performance measures. Its measures included direct labor versus budget, indirect material costs versus budget, inventory turns, controllable costs versus budget, an efficiency measure, scrap costs by workcenter, outbound on-time deliveries, and inbound on-time deliveries.

Over time, Talan Products’ measures have changed somewhat, with some dropping out, new ones added, and some staying the same. The company has also started using 12-month moving averages to monitor progress on the measures. The measures are reviewed monthly, with declining measures getting attention. As the company meets performance targets, new ones are set. Use of the performance measurement system has given Talan management a better understanding of the company.<sup>12</sup>

a financial burden to all sizes and types of organizations, and represent an even greater concern for companies trying to maintain and improve competitiveness.

A study performed by Pennsylvania-based Strategic Value Analysis in Healthcare found that for at least one-third of U.S. hospitals, inventories were excessive for a number of reasons. These included the stocking of out-of-date items and low-usage items, carrying too much safety stock, lengthy order lead times, double stocking, and poorly determined EOQs. One of the hospital clients established an inventory reduction program—it generated a list of products that hadn’t moved in three months, then held on to the more critical ones while disposing of or returning the rest. Items that were stored for only one department were transferred to the using departments. It analyzed usage patterns and discovered it could order many items more often and in smaller quantities. As a result, the hospital was able to reduce inventories by over \$92,000 in the first three months without impacting its customer service capabilities.<sup>13</sup>

As inventory management performance improves, the firm should notice improvements in customer retention, competitiveness, and economic success. The nearby Manufacturing Spotlight describes how a tooling company designed a useful and company-specific set of performance measures that proved to be very beneficial for the company. A number of useful inventory-oriented performance measures are shown in Table 7.5.<sup>14</sup>

All of the measures shown in Table 7.5 are directly or indirectly related to the firm’s ability to manage inventories. The final measure, cash-to-cash cycle time, provides an over-all view of the number of days of working capital tied up in managing inventories. For this measure, inventory days of supply (IDS) can be calculated as:

$$IDS = \frac{(\text{Avg. Inventory } \$)}{(\text{Annualized COGS} / 365)},$$

the days of receivables outstanding (DRO) can be calculated as:

$$DRO = \frac{(\text{Avg. Receivables } \$)}{(\text{Annualized Credit Revenues} / 365)},$$

and the days of payables outstanding (DPO) can be calculated as:

$$\text{DPO} = \frac{(\text{Avg. Payables}\$)}{(\text{Annualized Materials Costs} / 365)}$$

To interpret the results, the **inventory days of supply** tell management about how long inventory will be held before it is sold. A high IDS indicates too much inventory is being held, which will cause high inventory carrying costs. A low IDS indicates that not enough inventory is being held, which can create stockouts. Some analysts might recommend an IDS of about 40, but this varies based on industry norms.

The **days of receivables outstanding** (also called days of sales outstanding) is used to measure the average number of days it takes a company to collect what is owed to it after a credit sale has been completed. Put in fewer words, it is the average collection period. A low DRO is good, since the faster a company collects cash, the faster it can reinvest that cash to make more sales. Thus, a company with an increasing DRO over time is becoming less efficient, while a company with a decreasing DRO over time is becoming more efficient. A DRO of 40 to 50 might be considered normal.

**Days payable outstanding** tells about how long it takes a company to pay its creditors, such as suppliers. The longer the firm takes to pay its creditors, the more money the company has on-hand, but the less happy creditors will be. They may refuse to extend credit in the future, or they may offer less favorable payment terms. Again, the DPO varies by industry, but a DPO of about 30 is considered normal.

**Cash-to-cash cycle time** is commonly viewed as one of the best overall measures of inventory performance. It encompasses a number of contributing activities such as inventory speed, quality, and cost. The CCCT (also called the cash conversion cycle) indicates how long cash is tied up in the main cash-producing and cash-consuming areas: receivables, payables, and inventory. Normally, the lower the CCCT, the better, but too low can indicate low inventories and potential service issues, and very high days might indicate potential supplier issues.

**inventory days of supply** An inventory performance measure that tells management how long inventory is held before it is sold.

**days of receivables outstanding** An inventory performance measure that indicates the average number of days it takes a company to collect what is owed to it after a credit sale has been completed.

**days payable outstanding** An inventory performance measure that tells about how long it takes a company to pay its creditors, such as suppliers.

**cash-to-cash cycle time** An inventory performance measure indicating how long cash is tied up in the main cash-producing and cash-consuming areas of receivables, payables, and inventory.

**Table 7.5** Inventory-Oriented Performance Measures

Performance Measure	Description
<b>Delivery Performance</b>	(Total on-time and full orders)/(Total orders)
<b>Order Fulfillment Lead Time</b>	Average time from customer authorization of sales order to receipt of product
<b>Stockouts</b>	(Number of backorders or stockout complaints)/(Total orders)
<b>Back Order Duration</b>	Average order fulfillment lead time for customer orders not filled in full
<b>Other Lead Time measures:</b>	
<b>Manufacturing Lead Time</b>	Average manufacturing order start date to order ship date
<b>Warehouse Lead Time</b>	Average warehouse order receipt date to ship date
<b>Shipment Lead Time</b>	Average warehouse ship date to customer receipt date
<b>Response Time</b>	Average time to respond to an unplanned 20% increase or decrease in demand
<b>Total Inventory Management Cost</b>	Includes order management, customer service, warehousing, transportation, purchasing, supplier management, supply/demand planning, inventory holding, and returns/warranty management costs
<b>Cash-to-Cash Cycle Time</b>	(inventory days of supply + days of receivables outstanding) – days of payables outstanding



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## SUMMARY

This chapter introduced a wide range of inventory management topics, all of which are very important to the continued success of firms and their supply chain trading partners. The chapter discussed the processes, benefits, and challenges of inventory management, beginning with a general discussion of the types and functions of inventory,

continuing with discussions of independent demand inventory management methods, and ending with a discussion of monitoring inventory management performance. Effective inventory management practices can enable the firm to reduce costs, while still providing high levels of customer service.

## KEY TERMS

ABC inventory classification, 199  
 Anticipation inventories, 185  
 Bullwhip effect, 187  
 Cash-to-cash cycle time, 203  
 Cycle inventories, 185  
 Days payable outstanding, 203  
 Days of receivables outstanding, 203  
 Dependent demand, 187  
 Economic order quantity, 188  
 Finished goods, 184  
 Hedge inventories, 185  
 Independent demand, 187  
 Inventory carrying costs, 186  
 Inventory days of supply, 203  
 Inventory management performance, 201  
 Maintenance, repair, and operating supplies, 184  
 Optimal review period, 197  
 Order costs, 186

Order lead time, 188  
 Periodic review model, 197  
 Probabilistic demand and lead time reorder point model, 195  
 Probabilistic demand reorder point model, 192  
 Purchase cost, 186  
 Quantity discount model, 191  
 Raw materials, 184  
 Reorder point, 188  
 Robust model, 189  
 Safety stocks, 185  
 Service level, 195  
 Stockout costs, 186  
 Target inventory level, 198  
 Total annual inventory costs, 188  
 Transportation inventories, 185  
 Work-in-process, 184

## FORMULA REVIEW

### Annual order cost:

$O = \frac{D}{Q}S$ , where  $D$  = annual demand (units/year),  
 $Q$  = purchase order quantity (units), and  $S$  = cost of one purchase order (\$).

Number of orders per year =  $D/Q$ .

Number of days between orders =  $Q/d$ , where  $d$  = daily or average daily demand.

### Annual inventory carrying cost:

$I = \frac{Q}{2}iC$ , where  $Q$  = purchase order quantity (units),  
 $i$  = carrying cost rate per unit per year (%/year), and  
 $C$  = purchase cost of one unit (\$/unit).

### Economic order quantity:

$EOQ = \sqrt{\frac{2SD}{iC}}$ , where  $S$ ,  $D$ ,  $i$ ,  $C$  are defined as above.

**Constant demand reorder point:**

$ROP = d(L)$ , where  $d$  = constant daily demand and  $L$  = purchase order lead time.

**Probabilistic demand, constant lead time reorder point:**

$ROP = \bar{d}(L) + Z(\sigma_L)$ , where  $\bar{d}$  = average daily demand,  $Z$  = number of standard deviations required for a desired service level, and  $\sigma_L$  = standard deviation of lead time demand.

**Probabilistic demand and lead time reorder point:**

$ROP = \bar{d}(\bar{L}) + Z\sqrt{\bar{L}\sigma_d^2 + \bar{d}^2\sigma_L^2}$ , where  $\bar{L}$  = average order lead time,  $\sigma_d^2$  = variance of daily demand, and  $\sigma_L^2$  = variance of order lead time.

**Optimal review period for the periodic review model:**

$P = \frac{EOQ}{\bar{d}}$ , where  $P$  = review period (in days),  
 $\bar{d}$  = average daily demand.

**Target inventory level for the periodic review model:**

$T = \bar{d}(P+L) + Z(\sigma_{P+L})$ , where  $\sigma_{P+L}$  = standard deviation of (fixed review period + lead time) demand.

**Order quantity for periodic review model:**

$Q_i = T - K_i$ , where  $K_i$  = inventory on-hand in review period  $i$ .

**Inventory days of supply:**

$$IDS = \frac{(\text{Avg. Inventory } \$)}{(\text{Annualized COGS} / 365)}$$

**Days receivables outstanding:**

$$DRO = \frac{(\text{Avg. Receivables } \$)}{(\text{Annualized Revenues} / 365)}$$

**Days payables outstanding:**

$$DPO = \frac{(\text{Avg. Payables } \$)}{(\text{Annualized Materials Costs} / 365)}$$

**Cash-to-cash cycle time:**

$$CCCT = IDS + DRO - DPO$$

## SOLVED PROBLEMS

1. The annual demand forecast at Nena's Shoes is 12,000 pairs. If the order cost is \$50, the average purchase price is \$22, the carrying cost is 25% per year, and the purchase order lead time is 10 days, then:

- What is the EOQ size of each order?
- How many orders per year will be made?
- What is the time between each order?
- What is the reorder point?
- What is the total annual inventory cost?
- What is the order policy?

**Answer:**

a.  $EOQ = \sqrt{\frac{2SD}{iC}} = \sqrt{\frac{2(50)(12000)}{0.25(22)}} = 467$  pairs

b. No. orders per year =  $\frac{D}{EOQ} = \frac{12000}{467} = 25.7$  orders

c. Time between orders =  $\frac{EOQ}{d} = \frac{467}{12000/365} = 14.2$  days

d.  $ROP = d \times L = (12,000/365)10 = 328.8$  pairs.

e.  $TIC = O + I = \frac{D}{EOQ}(S) + \frac{Q}{2}iC = 25.7(50) + \frac{467}{2}(0.25)(22) = 1,285 + 1,284 = \$2,569$

- f. Order policy is to order 467 pairs of shoes every 14 days or when there are 329 pairs of shoes in stock.

2. The manager at Robert's Cigars wants to determine the lowest cost order policy given the following purchase discounts offered: Cigar costs are \$4 each for orders less than 500; \$3.50 each for orders of 500 – 1,000; and \$3.25 each for orders greater than 1,000. The order cost = \$75; annual demand forecast = 5,500 cigars; inventory carrying cost = 30% per year.

**Answer:**

Step 1. Determine the 3 EOQs—for \$4 cigars,

$$EOQ = \sqrt{\frac{2(75)(5500)}{0.3(4)}} = 829 \text{ (infeasible, since the EOQ must be } < 500 \text{).}$$

For \$3.50 cigars,

$$EOQ = \sqrt{\frac{2(75)(5500)}{0.3(3.50)}} = 886 \text{ (feasible range, since } 500 < 886 < 1,000 \text{).}$$

since  $EOQ > 500$  but  $< 1000$ ). For \$3.25 cigars,

$$EOQ = \sqrt{\frac{2(75)(5500)}{0.3(3.25)}} = 920 \text{ (infeasible, since}$$

$EOQ < 1,000$ , so must order 1,001 to get the discount).

Step 2. Calculate the total annual inventory costs for the \$3.50 and the \$3.25 cigars:

$$\begin{aligned} TIC_{3.50} &= O + I + P = \frac{D}{EOQ}(S) + \frac{Q}{2}iC + \\ D \times C &= \frac{5500}{886}(75) + \frac{886}{2}(.3) \\ &= (3.50) + 5,500(3.50) = \$465.58 \\ &+ \$465.15 + \$19,250 = \$20,180.73 \end{aligned}$$

$$\begin{aligned} TIC_{3.25} &= O + I + P = \frac{5500}{1001}(75) + \frac{1001}{2}(.3)(3.25) \\ &+ 5500(3.25) = \$412.09 + \$487.99 + \\ &+ \$17,875 = \$18,775.08 \end{aligned}$$

So the lowest cost order policy is to order 1,001 cigars at a time.

3. Jaimie's Pizza-to-Go makes and delivers pizzas and wants to know the reorder point for pizza boxes, given the following information: Average daily demand is 125 pizzas, with a daily standard deviation of 22 pizzas. The lead time for pizza box purchases is four days. It wants a 98% service level.

**Answer:**

$$\begin{aligned} ROP &= \bar{d}(L) + Z(\sigma_L) = 125(4) + 2.06(22) \\ &(\sqrt{4}) = 500 + 90.6 = 591 \end{aligned}$$

4. Taylor's Pizza-Down-and-Dirty makes and delivers pizzas. It wants to know the reorder point for pizza boxes, given the following information: Average daily demand is 125 pizzas, with a daily standard deviation of demand of 22 pizzas; average lead time for pizza boxes is four days, with a lead time standard deviation of two days. It wants a 98% service level.

**Answer:**

$$\begin{aligned} ROP &= \bar{d}(\bar{L}) + Z\sqrt{\bar{L}\sigma_d^2 + \bar{d}^2\sigma_L^2} = 125(4) + \\ &2.06\sqrt{4(22)^2 + 125^2(2)^2} = 500 + \\ &2.06(250.2) = 1015 \end{aligned}$$

5. Luke's Speedy Pizzas uses a pizza box supplier that has a sales rep come by weekly to order boxes. Luke wants a 98% service level. Its average daily demand is 125 pizzas, with a daily standard deviation of demand of 22 pizzas; lead time for pizza boxes is four days. If there are 420 pizza boxes when the rep comes by, how many boxes should be ordered?

**Answer:**

$$T = \bar{d}(P+L) + Z(\sigma_{P+L}) = 125(7+4) + 2.06(\sqrt{11})(22) = 1525$$

So the rep should order  $1,525 - 420 = 1,105$  boxes.

6. Given the following information, separate the inventory items using the ABC inventory classification approach.

**Answer:**

The answer is shown in the red column above. The A-items constitute 58.8% of the annual spend, the B-items were a total of 36.8%, and the C-items were 4.4% of annual spend.

Item SKU	Cost/Unit (\$)	Forecasted Annual Demand	Projected Annual Spend (\$)	Percent of Spend (Class)
108	116.50	322	37,513	2.7 (C)
102	112.40	1500	168,600	12.2 (B)
197	24.13	4922	118,768	8.6 (B)
126	422.95	875	370,081	26.7 (A)
136	240.99	1850	445,832	32.1 (A)
125	555.00	400	222,000	16.0 (B)
179	187.25	120	22,470	1.6 (C)
116	6.80	235	1,598	0.1 (C)
			1,386,862	

7. For the following information, what are the inventory days of supply, days receivables outstanding, days payables outstanding, and cash-to-cash cycle time?

Inventory on-hand at beginning of the year = \$1.75 million; inventory on-hand at end of the year = \$2.15 million; annual cost of goods sold = \$11.25 million; average annual accounts receivable = \$526,000; annual credit sales = \$15.45 million; beginning of year accounts payable = \$1.3 million; end of year accounts payable = \$1.08 million; total annual purchases = 14.2 million

**Answer:**

$$\begin{aligned} \text{IDS} &= \frac{(\text{Avg. Inventory } \$)}{(\text{Annualized COGS}/365)} \\ &= \frac{(1.75 + 2.15)^2}{11.25/365} = 63.3 \text{ days} \end{aligned}$$

$$\begin{aligned} \text{DRO} &= \frac{(\text{Avg. Receivables } \$)}{(\text{Annualized Credit Revenues} / 365)} \\ &= \frac{526,000}{15,450,000 / 365} = 12.4 \text{ days} \end{aligned}$$

$$\begin{aligned} \text{DPO} &= \frac{(\text{Avg. Payables } \$)}{(\text{Annualized Materials Costs} / 365)} \\ &= \frac{(1.3 + 1.08) / 2}{14.2 / 365} = 30.6 \text{ days} \end{aligned}$$

$$\text{CCCT} = \text{IDS} + \text{DRO} - \text{DPO} = 63.3 + 12.4 - 30.6 = 45.1 \text{ days}$$

## REVIEW QUESTIONS

- Your boss tells you to buy a one-year supply of toilet paper for the company. What type of inventory is this?
- List and describe the five functions of inventory.
- What are all of the various types of inventory costs?
- List some of the causes of stockouts.
- Define the bullwhip effect and its impact on supply chain inventories.
- Define independent and dependent demand, and provide some examples of each.
- What items are included in total annual inventory costs?
- Why is the EOQ model described as “robust”?
- Explain the assumptions of the EOQ model.
- How do changes in demand, order cost, and carrying cost affect the EOQ?
- What determines the level of safety stock to be used in the probabilistic demand reorder point model?
- How is the EOQ used in the periodic review model?
- What is the ABC inventory classification, and how is it used?
- Why are inventory management performance measures important?

## DISCUSSION QUESTIONS

- Why do you think inventory is considered a “necessary evil” in organizations?
- How would you reduce stockout risk at a hospital? At a high-end retailer? At Walmart?
- Discuss the relationship between the bullwhip effect and supply chain inventories, and what can be done to manage it.
- Why does the EOQ only seek to minimize annual order cost and annual inventory carrying cost? What happened to stockout cost and purchase cost?
- How does the quantity discount model differ from the EOQ model? Is the EOQ still used?
- Why might it be cheaper to order a large quantity of price-discounted merchandise from a supplier rather than the appropriate EOQ amount? Won't the annual carrying cost be prohibitively high?
- Explain the order policy used when demand is assumed to be variable. Is the EOQ still useful here?
- In looking at the ROP formula with variable demand, what is the expected service level when Z is zero? What is the safety stock level when Z is zero? What is the maximum value of Z?
- When both demand and purchase lead time vary, why is the required safety stock higher when compared to the variable demand ROP model, for the same service level?

10. Describe several cases when a periodic review model would be preferred to an ROP model.
11. What can be said about order lead times and safety stocks in actively managed, successful supply chains?
12. Could cash-to-cash cycle time be negative? How? Would that be good?
13. What would be some good inventory management performance measures for a fast-food company? A bicycle repair shop? A big-box retailer?

## EXERCISES AND PROJECTS

1. Write a paper on managing the bullwhip effect, and provide examples of companies that have successfully managed theirs.
2. Search the Internet and write a report on five common inventory problems and how companies can avoid these problems.
3. Search the Internet for a publicly held firm with annual reports. Find the balance sheets and income statements, and then calculate and discuss the IDS, DRO, DPO, and CCCT.

## PROBLEMS

Use the following information for Problems 1 through 5:

Kathy owns a neighborhood hot dog stand, and wants to determine some good order policies for hot dogs. She estimates her annual demand to be constant and equal to 10,000 hot dogs. Her order cost is \$20, the carrying cost rate is 40% per year, the purchase cost is \$0.20 per hot dog, and the order lead time is two days.

1. What is the optimal order quantity?
2. What is the annual order cost?
3. What is the annual inventory carrying cost and the relevant total annual inventory cost?
4. How many orders per year will Kathy make? How many days will there be, between orders?
5. What is the reorder point? What is Kathy's optimal order policy?
6. Using the information in Problem 1, if Kathy's carrying cost rate dropped by half, to 20% per year, how would this impact Problems 1 through 5?
7. Using the information in Problem 1, if Kathy's order cost increased to \$100, how does this impact Problems 1 through 5?
8. Find the economic order quantity and the reorder point for the following information: annual demand is 22,500 units; order cost is \$70 per order; annual inventory carrying cost is \$5 per unit; the order lead time is 10 days; and the business operates 300 days per year.

Use the following information for Problems 9 and 10:

Grebbly's Rodeo Tack & Boots sells gear to rodeo industry customers and has been offered discounts for the purchase of some alligator-hide boots from its longtime boot supplier. The pricing alternatives for the alligator boots are: \$62 per pair for 1–299 pair purchased; \$57 per pair for 300–599 units purchased; and \$54 per pair for 600 or more units purchased. Grebbly's average order cost is \$25 per order; the forecasted annual demand for alligator boots is 1,200 pair; and the inventory carrying cost rate is 24% per year.

9. Calculate the EOQ for each of the three purchase prices. Which EOQs are valid?
10. Which purchasing alternative should Grebbly's take? What are the total annual inventory costs for the valid alternatives?
11. The Big Cheese Pizza Parlor buys lots of pizza boxes. It normally pays \$1 per box when ordering from its supplier. Based on its annual forecast for pizza demand, its demand for boxes is estimated to be 10,000 units for the year. It costs \$25 to place an order, and its holding cost for boxes is 25% of the cost of a box per year. The supplier tells the Big Cheese Pizza Parlor that she can sell the boxes for \$0.95 each if the restaurant buys a minimum of 5,000 at a time. Should it take the discount, and what is the total cost?
12. Average demand is 2,500 units per year; order cost is \$50 per order; holding cost rate is 20% of the purchase cost per unit per year; and the cost of one unit is \$42. What is the total inventory cost per year? If a cost reduction per unit of \$1 can be achieved by buying 1,000 at a time, should the buyer take the discount? Justify your answer.

13. The average demand is equal to 10 units per day, the order lead time is 7 days, and the standard deviation of the lead time demand is 4 units. If a 95% service level is desired, what is the reorder point?
14. Roy and Gayle's Fix-It Shop purchased a new automated inventory control software application, and it wanted to put ROPs on all of its purchased tools and supplies. After forecasting the demand for items for the upcoming year, it was ready to start calculating ROPs. Three of the items are shown below, along with the forecasted annual demands, purchase lead times, lead time demand standard deviation levels, and desired service levels. Calculate the ROPs for the three items and their safety stock levels. Assume the store is open 365 days per year.

Item	Annual Demand	Lead time	Std. Dev. L.t.d.	Required Serv. Level
Duct Tape	2300 rolls	12 days	6 rolls	99%
Super Glue	1800 bottles	6 days	4 bottles	90%
Hammer	650 hammers	21 days	3 hammers	80%

15. Phyllis was just hired as the new purchasing manager at Rich Furniture. She decided to recalculate all of its ROPs, since she noticed that many of the suppliers' delivery times varied substantially from one order to the next. Phyllis asked Mary Jane, her buyer, to recalculate the first one (a desk), to make sure it was done correctly. Phyllis also wanted to know the safety stock required. The upcoming annual demand forecast was 950 desks. The purchase order lead times varied, with an average of 18 days and a standard deviation of 6 days. The daily demand also varied, with an average of three units per day, and a standard deviation of five desks per day. Phyllis would like to maintain a 98% service level.

Use the following information for Problems 16 through 18:

The manager at Skyler's Pet Supplies decides to order catnip treats from a supplier that visits whenever the manager calls, and then makes orders. The annual demand for cat treats is 8,000, with a daily standard deviation of 6 treats. The store is open 365 days per year. Their order cost is \$35, the treats are \$1.25 each, and the carrying cost rate is 28% per year. The order lead time is always 5 days. The manager wants a 95% service level.

16. What is the EOQ?
17. What is the optimal review period?
18. What is the target quantity or order-up-to-level? If there were 225 cat treats in inventory when the supplier visited, what would be the order size?
19. Tom uses a fixed review period inventory system in his store. He counts his inventory every 30 days and then makes an order. Ten days later his order shows up from the supplier. On one ordering occasion, he counts and finds 81 units in inventory. If the average daily demand is 10 units, the standard deviation of the (review period + lead time) demand is 17 units, and he desires a probability of not stocking out of 96%, how many units should Tom order?
20. Classify the following items using the ABC inventory classification approach. Which items should be monitored most closely, and which ones should have the least amount of safety stock?

Item	Cost/Unit (\$)	Forecasted Annual Demand
1	6.40	1,700
2	7.80	7,500
3	17.49	6,240
4	44.00	260
5	105.99	150
6	345.00	300

21. Mennitt's Bowlarama wants to determine its inventory management performance during its past year of operations. Calculate its inventory days of supply, days receivables outstanding, days payables outstanding, and cash-to-cash cycle time, and then assess its performance. Use the following information: Inventory on-hand at beginning of the year = \$156,000; inventory on-hand at end of the year = \$145,000; annual cost of goods sold = \$895,000; average annual accounts receivable = \$26,000; annual credit sales = \$68,000; beginning of year accounts payable = \$130,000; end of year accounts payable = \$186,000; total annual purchases = \$1.05 million.

## CASE STUDIES

### CASE 1: Inventory Problems at Three Spoons Market

Randy is the owner of Three Spoons Market. Three Spoons is an upscale tapas restaurant in a town of about 200,000 people. According to both Yelp and Trip Advisory, it is the highest-rated restaurant in town. Randy had been having trouble with inventory management (he runs out of some items while others go bad) and has brought you in as a consultant to help, due to your background in inventory management. The menu at the restaurant changes monthly, and there are daily specials.

Randy follows what other restaurant owners are doing to improve their bottom line—he reads trade publications and online blogs. He also tries to keep up with trends in other industries that may help him manage better. He recently read about the success small-job shops have had with managing inventory by classifying inventory as A, B, or C. As Randy thinks about his business, it is really a job shop, since food is prepared after the customer orders from the menu. The food is prepared to customer tastes and requirements. He is not exactly sure if an ABC inventory plan will work for his restaurant, but has hired you to provide a recommendation. All the ingredients used in the dishes are either dried or fresh. Nothing frozen or processed is put in the food. Customers can request alterations in menu items during ordering. A detail of the inventories at the restaurant are as follows:

- *Condiments.* Used for additional flavoring of foods at the table. Can be stored for long periods of time. There are five different condiments available, and multiple tables may need the same condiments at the same time. These items represent less than 0.5% of food costs.
- *Spices and dried fruits.* Used in most dishes, and can be stored for long periods of time without compromising the taste of the items. There are about 50 different spices and fruits that are stocked. Some can be substituted for others. These items represent less than 5% of the food costs for the various dishes.
- *Oils.* Used to prepare items and as an ingredient in some dishes. Have shelf lives of one week to one month. There are 10 different oils that are stocked.

Two or three can be substituted, but the others have a unique taste. These items represent about 10–15% of the food costs and preparation costs of the various dishes.

- *Fresh vegetables and herbs.* Have a shelf life of two days to one week. These items are delivered in a truck that comes twice a week, but in some cases have to be ordered a week in advance. In an emergency, these items can be found at a local grocery store. These items represent between 10–70% of the food costs of the various dishes, depending on if the dish contains meat.
- *Fresh fruits.* Have a shelf life of two to four days. These items are unique to the dishes on the menu. They are not usually found in a local grocery store, but in a pinch someone can drive an hour to a distributor to pick them up, if in stock. These items are delivered twice per week. They represent about 10% of the food costs.
- *Meats.* Have a shelf life of two to four days. These items are unique to the dishes on the menu. They are not usually found in the local grocery store, but are available from a distributor, if in stock. These items are delivered twice a week. They represent up to 60% of the food costs.
- *Dairy.* Have a shelf life of one week. These items are usually delivered three times per week and can also be found locally at a grocery store. The items represent less than 5% of the costs of the food items.

#### DISCUSSION QUESTIONS

1. What are the advantages and disadvantages of having an ABC inventory plan at the restaurant?
2. What items would you classify in each category?
3. Are stockouts acceptable in this type of business? Why, or why not?
4. Would the creation of more work-in-process or finished goods inventory be beneficial to the owner? Why, or why not?

*Note:* Written by Jeffrey W. Fahrenwald, MBA, Rockford University, Rockford, IL. This case was prepared solely to provide material for class discussion. The author does not intend to illustrate either effective or ineffective handling of a managerial situation.

### CASE 2: Inventory Management at Protech Logistics

Pat is the newly hired manager of warehouse operations for Protech Logistics, a distributor that sells MRO (maintenance, repair, and operating) items to various governmental

and nongovernmental organizations throughout the United States. She has been asked by the president of Protech to do a study of various types of inventory systems. The report

should contain an evaluation of how Protech currently manages its inventory, along with recommendations (if applicable) for improving the system.

Historically, the company has simply ordered items four times a year based on past sales. This system has served the company well (it has been profitable for the past 20 years), but with increased competition and tightening margins, the president is fearful that in the future, this type of inventory system could hurt organizational financial performance and customer service. The organization stocks over 10,000 different items (SKUs). Costs of the items range from about \$0.50 to \$10,000. Sales of items run from one or two per year to hundreds of thousands per year. Currently, there are about 100 SKUs in the warehouse, with a total procurement cost of \$50,000, that have not sold a single unit in more than two years.

Most (at least 80%) of the items in the warehouse that cost over \$5,000 could be drop shipped directly to the customer from the supplier. Currently, this is only done for about 25% of the orders. There would be an additional cost for a drop ship; however, this cost could be offset against the cost of holding the item in the warehouse and the opportunity perhaps to downsize the warehouse.

*Note:* Written by Jeffrey W. Fahrenwald, MBA, Rockford University, Rockford, IL. This case was prepared solely to provide material for class discussion. The author does not intend to illustrate either effective or ineffective handling of a managerial situation.

The president would like to know more about various types of systems that could be available and wants Pat to make an evaluation of the current Protech system. She has read about various ABC and EOQ models and is not sure either model will work for an MRO supplier. She sees the ABC and EOQ models “at odds” with each other; however, she also thinks both models have the potential for saving money. On the other hand, the inventory system in place at Protech is simple and logical, and makes the process of ordering product routine. The president has also asked Pat to come up with a strategy to clear out items that have not sold for over two years, but does not want to sell these items at less than the procurement cost.

### DISCUSSION QUESTIONS

1. What are the strengths and weaknesses of the current system?
2. Would the use of EOQ potentially improve the system? Why, or why not?
3. Would some sort of ABC system be suitable for this type of operation? Explain.
4. How should Pat respond to the president with regard to selling the items that have not sold for the past two years?

## VIDEO CASE STUDY



Exclusive video case studies follow real companies as they make decisions, solve problems, overcome obstacles, and strategically use operation tools and techniques to create a competitive advantage. Interviews with industry professionals provide real-world context for chapter topics and accompanying assessments are included to enable students to check their understanding.

*Note:* Video Case Studies will be hosted on the open-access Sage edge site accompanying this text.

## LITTLEFIELD TECHNOLOGIES

Littlefield Technologies, developed by Sunil Kumar and Samuel C. Wood at the Stanford Graduate School of Business, is a factory simulation that allows students to interact with each other while developing their operations management skills. Students manage their factories by purchasing and selling machines, changing the inventory order quantity and trigger point, changing a scheduling parameter, and selecting among a choice of lead time quotes. Students make decisions

in response to historical records of inventory levels, queues, machine utilization, lead times, cash flows, and the team’s relative performance compared to the other competing teams. This is additional placeholder language to show the actual expected length of the Littlefield feature copy still to come. This is additional placeholder language to show the actual expected length of the Littlefield feature copy still to come. This is additional placeholder language to show the actual expected length.

*Note:* Littlefield Technologies simulations will be available for purchase as a bundle item with this text.



*Our experience has been that many times the process is not completely thought through, or the building is a series of additions, which does not work well for the product or the people. A lean design expert could give you an accounting for how much money can be wasted if 50 people are required to walk an extra 200 feet five times per day, for example.*

—GARY JAMES, engineering director, Frankfort Short Bruza<sup>1</sup>

*It's like a steel chain with one plastic link. Tell me what you are going to do by improving any one of those steel links without doing something about the plastic one. I use my lean toolbox once I find my constraint. Theory of Constraints leads me to the core problem.*

—BOB BUCKLEY, owner, True32 Custom Cabinetry<sup>2</sup>