Material Requirements Planning (MRP) and ERP

CHAPTER 14

CHAPTER OUTLINE

Alaska Airlines

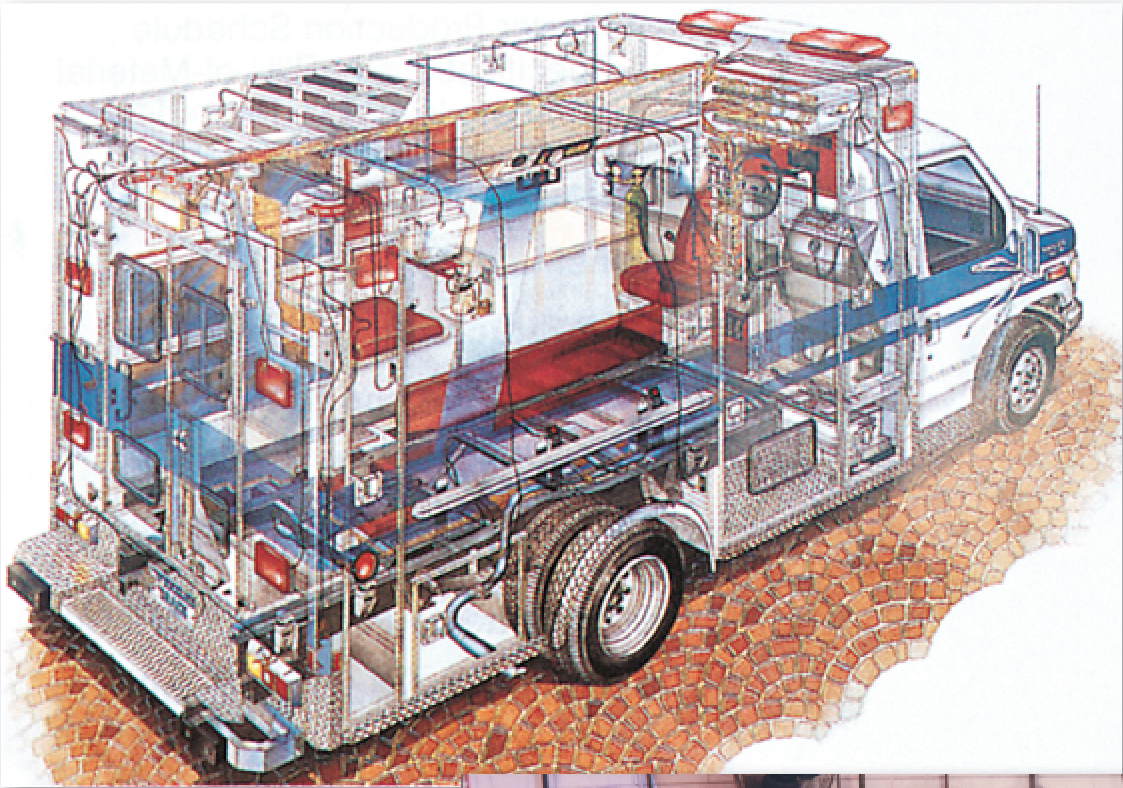
10 OM STRATEGY DECISIONS

- Design of Goods and Services
- Managing Quality
- Process Strategy
- Location Strategies
- Layout Strategies
- Human Resources
- Supply-Chain Management
- *Inventory Management*
  - Independent Demand (Ch. 12)
  - ***Dependent Demand (Ch. 14)***
  - Lean Operations (Ch. 16)
- Scheduling
- Maintenance

GLOBAL COMPANY PROFILE
Wheeled Coach

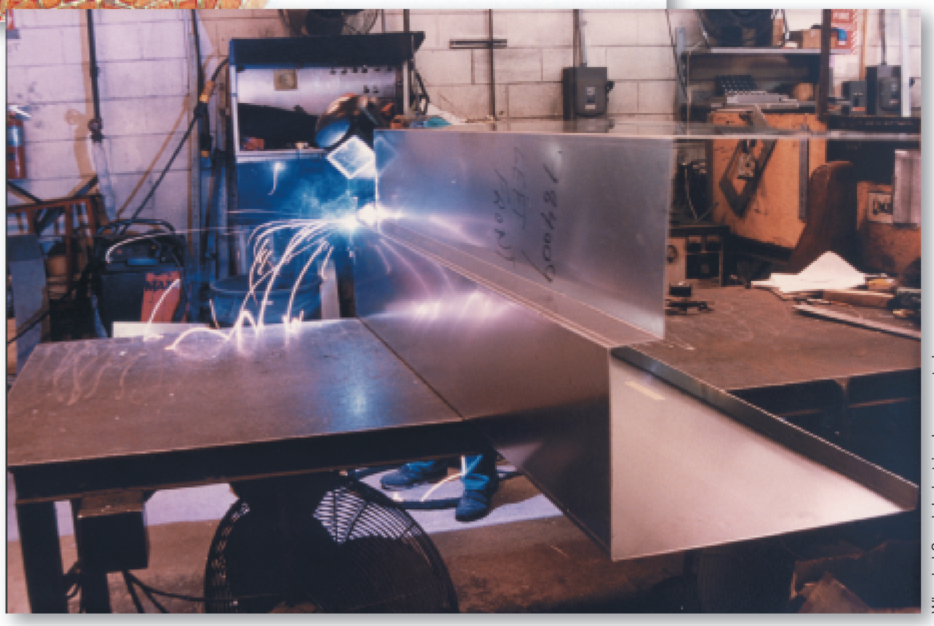
MRP Provides a Competitive Advantage for Wheeled Coach

Wheeled Coach, headquartered in Winter Park, Florida, is the largest manufacturer of ambulances in the world. The $200 million firm is an international competitor that sells more than 25% of its vehicles to markets outside the U.S. Twelve major ambulance designs are produced on assembly lines (i.e., a repetitive process) at the Florida plant, using 18,000 different



Wheeled Coach Industries Incorporated

This cutaway of one ambulance interior indicates the complexity of the product, which for some rural locations may be the equivalent of a hospital emergency room in miniature. To complicate production, virtually every ambulance is custom ordered. This customization necessitates precise orders, excellent bills of materials, exceptional inventory control from supplier to assembly, and an MRP system that works.



Wheeled Coach Industries Incorporated

Wheeled Coach uses work cells to feed the assembly line. It maintains a complete carpentry shop (to provide interior cabinetry), a paint shop (to prepare, paint, and detail each vehicle), an electrical shop (to provide for the complex electronics in a modern ambulance), an upholstery shop (to make interior seats and benches), and as shown here, a metal fabrication shop (to construct the shell of the ambulance).

inventory items, of which 6,000 are manufactured and 12,000 purchased. Most of the product line is custom designed and assembled to meet the specific and often unique requirements demanded by the ambulance's application and customer preferences.

This variety of products and the nature of the process demand good material requirements planning (MRP). Effective use of an MRP system requires accurate bills of material and inventory records. The Wheeled Coach system provides daily updates and has reduced inventory by more than 30% in just two years.

Wheeled Coach insists that four key tasks be performed properly. First, the material plan must meet both the requirements of the master schedule and the capabilities of the production facility. Second, the plan must be executed as designed. Third, inventory investment must be minimized through effective "time-phased" material deliveries, consignment inventories, and a constant review of purchase methods. Finally, excellent record integrity must be maintained. Record accuracy is recognized as a fundamental ingredient of Wheeled Coach's successful MRP program. Its cycle counters are charged with material audits that not only correct errors but also investigate and correct problems.

Wheeled Coach Industries uses MRP as the catalyst for low inventory, high quality, tight schedules, and accurate records. Wheeled Coach has found competitive advantage via MRP.

Wheeled Coach Industries Incorporated

On five parallel lines, ambulances move forward each day to the next workstation. The MRP system makes certain that just the materials needed at each station arrive overnight for assembly the next day.

Wheeled Coach Industries Incorporated

Here an employee is installing the wiring for an ambulance. There are an average of 15 miles of wire in a Wheeled Coach vehicle. This compares to 17 miles of wire in a sophisticated F-16 fighter jet.

LEARNING OBJECTIVES

Dependent Demand

STUDENT TIP "Dependent demand" means the demand for one item is related to the demand for another item.

Wheeled Coach, the subject of the *Global Company Profile*, and many other firms have found important benefits in material requirements planning (MRP). These benefits include (1) better response to customer orders as the result of improved adherence to schedules, (2) faster response to market changes, (3) improved utilization of facilities and labor, and (4) reduced inventory levels. Better response to customer orders and to the market wins orders and market share. Better utilization of facilities and labor yields higher productivity and return on investment. Less inventory frees up capital and floor space for other uses. These benefits are the result of a strategic decision to use a *dependent* inventory scheduling system. Demand for every component of an ambulance is dependent.

Demand for items is dependent when the relationship between the items can be determined. Therefore, once management receives an order or makes a forecast for the final product, quantities for all components can be computed. All components are dependent items. The Boeing Aircraft operations manager who schedules production of one plane per week, for example, knows the requirements down to the last rivet. For any product, all components of that product are dependent demand items. *More generally, for any product for which a schedule can be established, dependent techniques should be used.*

When the requirements of MRP are met, dependent models are preferable to the models for independent demand (EOQ) described in Chapter 12.[1] Dependent models are better not only for manufacturers and distributors but also for a wide variety of firms from restaurants to hospitals. The dependent technique used in a production environment is called **material requirements planning (MRP)**.

Material requirements planning (MRP)
A dependent demand technique that uses a bill-of-material, inventory, expected receipts, and a master production schedule to determine material requirements.

Because MRP provides such a clean structure for dependent demand, it has evolved as the basis for Enterprise Resource Planning (ERP). ERP is an information system for identifying and planning the enterprise-wide resources needed to take, make, ship, and account for customer orders. We will discuss ERP in the latter part of this chapter.

Dependent Inventory Model Requirements

Effective use of dependent inventory models requires that the operations manager know the following:

1. Master production schedule (what is to be made and when)
2. Specifications or bill of material (materials and parts required to make the product)
3. Inventory availability (what is in stock)
4. Purchase orders outstanding (what is on order, also called expected receipts)
5. Lead times (how long it takes to get various components)

We now discuss each of these requirements in the context of material requirements planning.

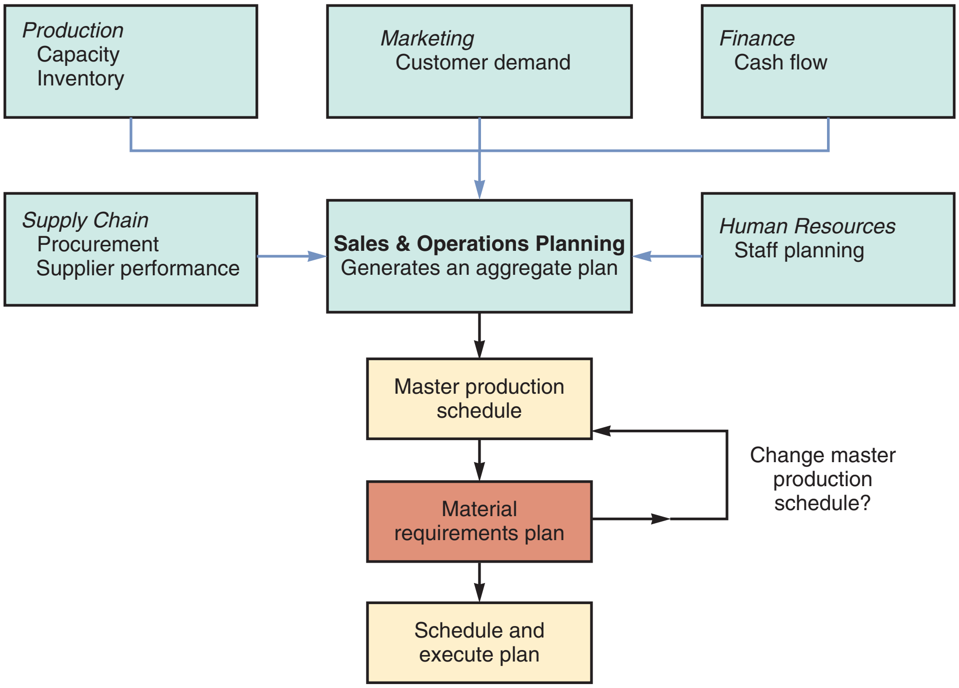


Figure 14.1

The Planning Process

Master Production Schedule

A **master production schedule (MPS)** specifies what is to be made (e.g., the number of finished products or items) and when. The schedule must be in accordance with an aggregate plan. The aggregate plan sets the overall level of output in broad terms (e.g., product families, standard hours, or dollar volume). The plan, usually developed by the sales and operations planning team, includes a variety of inputs, including financial data, customer demand, engineering capabilities, labor availability, inventory fluctuations, supplier performance, and other considerations. Each of these inputs contributes in its own way to the aggregate plan, as shown in Figure 14.1.

Master production schedule (MPS)
A timetable that specifies what is to be made (usually finished goods) and when.

As the planning process moves from the aggregate plan to execution, each of the lower-level plans must be feasible. When one is not, feedback to the next higher level is required to make the necessary adjustment. One of the major strengths of MRP is its ability to determine precisely the feasibility of a schedule within aggregate capacity constraints. This planning process can yield excellent results. The aggregate plan sets the upper and lower bounds on the master production schedule.

The master production schedule tells us how to satisfy demand by specifying what items to make and when. It *disaggregates* the aggregate plan. While the *aggregate plan* (as discussed in Chapter 13) is established in gross terms such as families of products or tons of steel, the *master production schedule* is established in terms of specific products. Figure 14.2 shows the master production schedules for three stereo models that flow from the aggregate plan for a family of stereo amplifiers.

Aggregate Plan
(Shows the total quantity of amplifiers)

Months	January	February
	1,500	1,200

Master Production Schedule
(Shows the specific type and quantity of amplifier to be produced)

Weeks	1	2	3	4	5	6	7	8
240-watt amplifier	100		100		100		100	
150-watt amplifier		500		500		450		450
75-watt amplifier			300				100	

Figure 14.2

The Aggregate Plan Is the Basis for Development of the Master Production Schedule

TABLE 14.1 Master Production Schedule for Chef John's Buffalo Chicken Mac & Cheese

GROSS REQUIREMENTS FOR CHEF JOHN'S BUFFALO CHICKEN MAC & CHEESE										
Day	6	7	8	9	10	11	12	13	14	and so on
Quantity	450		200	350	525		235	375		

Managers must adhere to the schedule for a reasonable length of time (usually a major portion of the production cycle—the time it takes to produce a product). Many organizations establish a master production schedule and establish a policy of not changing ("fixing") the near-term portion of the plan. This near-term portion of the plan is then referred to as the "fixed," "firm," or "frozen" schedule. Wheeled Coach, the subject of the *Global Company Profile* for this chapter, fixes the last 14 days of its schedule. Only changes farther out, beyond the fixed schedule, are permitted. The master production schedule is a "rolling" production schedule. For example, a fixed 7-week plan has an additional week added to it as each week is completed, so a 7-week fixed schedule is maintained. Note that the master production schedule is a statement of *what is to be produced;* it is *not* a forecast. The master schedule can be expressed in the following terms:

- A *customer order* in a job shop (make-to-order) company (examples: print shops, machine shops, fine-dining restaurants)
- *Modules* in a repetitive (assemble-to-order or forecast) company (examples: Harley-Davidson motorcycles, TVs, fast-food restaurant)
- An *end item* in a continuous (stock-to-forecast) company (examples: steel, beer, bread, light bulbs, paper)

VIDEO 14.1
When 18,500 Orlando Magic Fans Come to Dinner

A master production schedule for Chef John's "Buffalo Chicken Mac & Cheese" at the Orlando Magic's Amway Center is shown in Table 14.1.

Bills of Material

Bill of material (BOM)
A listing of the components, their description, and the quantity of each required to make one unit of a product.

Defining what goes into a product may seem simple, but it can be difficult in practice. As we noted in Chapter 5, to aid this process, manufactured items are defined via a bill of material. A **bill of material (BOM)** is a list of quantities of components, ingredients, and materials required to make a product. Individual drawings describe not only physical dimensions but also any special processing as well as the raw material from which each part is made. Chef John's recipe for Buffalo Chicken Mac & Cheese specifies ingredients and quantities, just as Wheeled Coach has a full set of drawings for an ambulance. Both are bills of material (although we call one a recipe, and they do vary somewhat in scope).

VIDEO 14.2
MRP at Wheeled Coach Ambulances

One way a bill of material defines a product is by providing a product structure. Example 1 shows how to develop the product structure and "explode" it to reveal the requirements for each component. A bill of material for item A in Example 1 consists of items B and C. Items above any level are called *parents*; items below any level are called *components* or *children*. By convention, the top level in a BOM is the 0 level.

Example 1

DEVELOPING A PRODUCT STRUCTURE AND GROSS REQUIREMENTS

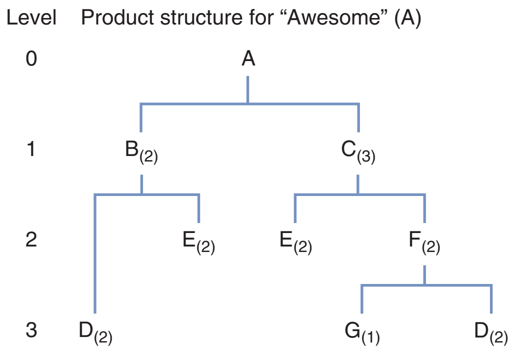
Speaker Kits, Inc., packages high-fidelity components for mail order. Components for the top-of-the-line speaker kit, "Awesome" (A), include 2 Bs and 3 Cs.

Each B consists of 2 Ds and 2 Es. Each of the Cs has 2 Fs and 2 Es. Each F includes 2 Ds and 1 G. It is an *awesome* sound system. (Most purchasers require hearing aids within 3 years, and at least one court case is pending because of structural damage to a men's dormitory.) As we can see, the demand for B, C, D, E, F, and G is completely dependent on the master production schedule for A—the Awesome speaker kits.

LO 14.1 *Develop* a product structure

APPROACH ▶ Given the preceding information, we construct a product structure and "explode" the requirements.

SOLUTION ▶ This structure has four levels: 0, 1, 2, and 3. There are four parents: A, B, C, and F. Each parent item has at least one level below it. Items B, C, D, E, F, and G are components because each item has at least one level above it. In this structure, B, C, and F are both parents and components. The number in parentheses indicates how many units of that particular item are needed to make the item immediately above it. Thus, $B_{(2)}$ means that it takes two units of B for every unit of A, and $F_{(2)}$ means that it takes two units of F for every unit of C.



Dragon_Fang/Shutterstock

Once we have developed the product structure, we can determine the number of units of each item required to satisfy demand for a new order of 50 Awesome speaker kits. We "explode" the requirements as shown:

Part B:	2 × number of As =	(2)(50) =	100
Part C:	3 × number of As =	(3)(50) =	150
Part D:	2 × number of Bs + 2 × number of Fs =	(2)(100) + (2)(300) =	800
Part E:	2 × number of Bs + 2 × number of Cs =	(2)(100) + (2)(150) =	500
Part F:	2 × number of Cs =	(2)(150) =	300
Part G:	1 × number of Fs =	(1)(300) =	300

INSIGHT ▶ We now have a visual picture of the Awesome speaker kit requirements and knowledge of the quantities required. Thus, for 50 units of A, we will need 100 units of B, 150 units of C, 800 units of D, 500 units of E, 300 units of F, and 300 units of G.

LEARNING EXERCISE ▶ If there are 100 Fs in stock, how many Ds do you need? [Answer: 600.]

RELATED PROBLEMS ▶ 14.1–14.4, 14.5a,b, 14.13a,b, 14.17a,b (14.20a,b are available in MyOMLab)

Bills of material not only specify requirements but also are useful for costing, and they can serve as a list of items to be issued to production or assembly personnel. When bills of material are used in this way, they are usually called *pick lists*.

Modular Bills Bills of material may be organized around product modules (see Chapter 5). *Modules* are not final products to be sold, but are components that can be produced and assembled into units. They are often major components of the final product or product options. Bills of material for modules are called **modular bills**. Modular bills are convenient because production scheduling and production are often facilitated by organizing around relatively few modules rather than a multitude of final assemblies. For instance, a firm may make 138,000 different final products but may have only 40 modules that are mixed and matched to produce those 138,000 final products. The firm builds an aggregate production plan and prepares its master production schedule for the 40 modules, not the 138,000

Modular bills
Bills of material organized by major subassemblies or by product options.

configurations of the final product. This approach allows the MPS to be prepared for a reasonable number of items. The 40 modules can then be configured for specific orders at final assembly.

Planning bills (or kits)
Material groupings created in order to assign an artificial parent to a bill of material; also called "pseudo" bills.

Phantom bills of material
Bills of material for components, usually assemblies, that exist only temporarily; they are never inventoried.

Planning Bills and Phantom Bills Two other special kinds of bills of material are planning bills and phantom bills. **Planning bills** (sometimes called "pseudo" bills, or super bills) are created in order to assign an artificial parent to the bill of material. Such bills are used (1) when we want to group subassemblies so the number of items to be scheduled is reduced and (2) when we want to issue "kits" to the production department. For instance, it may not be efficient to issue inexpensive items such as washers and cotter pins with each of numerous subassemblies, so we call this a *kit* and generate a planning bill. The planning bill specifies the *kit* to be issued. Consequently, a planning bill may also be known as **kitted material,** or **kit**. **Phantom bills of material** are bills of material for components, usually subassemblies, that exist only temporarily. These components go directly into another assembly and are never inventoried. Therefore, components of phantom bills of material are coded to receive special treatment; lead times are zero, and they are handled as an integral part of their parent item. An example is a transmission shaft with gears and bearings assembly that is placed directly into a transmission.

Low-level coding
A number that identifies items at the lowest level at which they occur.

Low-Level Coding Low-level coding of an item in a BOM is necessary when identical items exist at various levels in the BOM. **Low-level coding** means that the item is coded at the lowest level at which it occurs. For example, item D in Example 1 is coded at the lowest level at which it is used. Item D could be coded as part of B and occur at level 2. However, because D is also part of F, and F is level 2, item D becomes a level-3 item. Low-level coding is a convention to allow easy computing of the requirements of an item.

Accurate Inventory Records

As we saw in Chapter 12, knowledge of what is in stock is the result of good inventory management. Good inventory management is an absolute necessity for an MRP system to work. If the firm does not exceed 99% record accuracy, then material requirements planning will not work.[2]

Purchase Orders Outstanding

Lead time
In purchasing systems, the time between recognition of the need for an order and receiving it; in production systems, it is the order, wait, move, queue, setup, and run times for each component.

Knowledge of outstanding orders exists as a by-product of well-managed purchasing and inventory-control departments. When purchase orders are executed, records of those orders and their scheduled delivery dates must be available to production personnel. Only with good purchasing data can managers prepare meaningful production plans and effectively execute an MRP system.

Lead Times for Components

Once managers determine when products are needed, they determine when to acquire them. The time required to acquire (that is, purchase, produce, or assemble) an item is known as **lead time**. Lead time for a manufactured item consists of *move*, *setup*, and *assembly* or *run times* for each component. For a purchased item, the lead time includes the time between recognition of need for an order and when it is available for production.

When the bill of material for Awesome speaker kits (As), in Example 1, is turned on its side and modified by adding lead times for each component (see Table 14.2), we then have a *time-phased product structure*. Time in this structure is shown on the horizontal axis of Figure 14.3 with item A due for completion in week 8. Each component is then offset to accommodate lead times.

TABLE 14.2
Lead Times for Awesome Speaker Kits (As)

COMPONENT	LEAD TIME
A	1 week
B	2 weeks
C	1 week
D	1 week
E	2 weeks
F	3 weeks
G	2 weeks

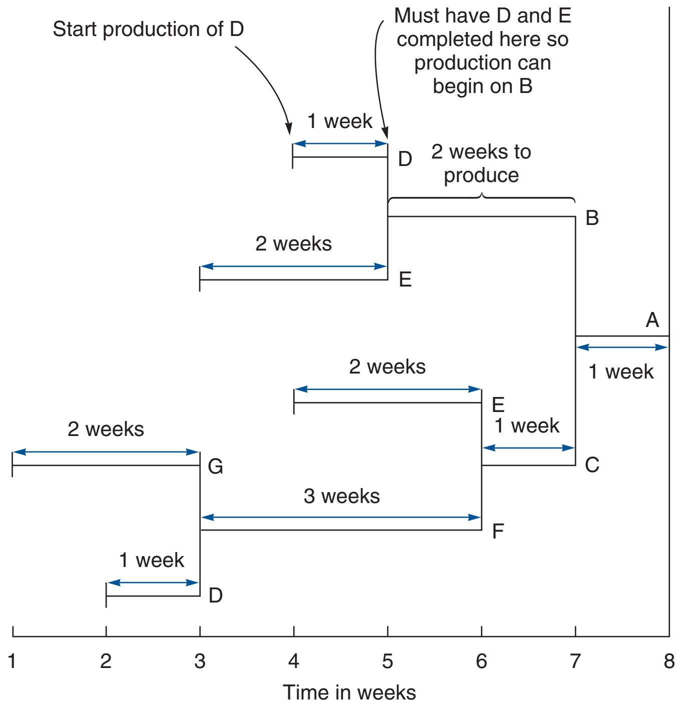


Figure 14.3

Time-Phased Product Structure

STUDENT TIP

This is a product structure on its side, with lead times.

MRP Structure

Although most MRP systems are computerized, the MRP procedure is straightforward, and we can illustrate a small one by hand. A master production schedule, a bill of material, inventory and purchase records, and lead times for each item are the ingredients of a material requirements planning system (see Figure 14.4).

Once these ingredients are available and accurate, the next step is to construct a gross material requirements plan. The **gross material requirements plan** is a schedule, as shown in Example 2. It combines a master production schedule (that requires one unit of A in week 8) and the time-phased schedule (Figure 14.3). It shows when an item must be ordered from suppliers if there is no inventory on hand or when the production of an item must be started to satisfy demand for the finished product by a particular date.

Gross material requirements plan

A schedule that shows the total demand for an item (prior to subtraction of on-hand inventory and scheduled receipts) and (1) when it must be ordered from suppliers, or (2) when production must be started to meet its demand by a particular date.

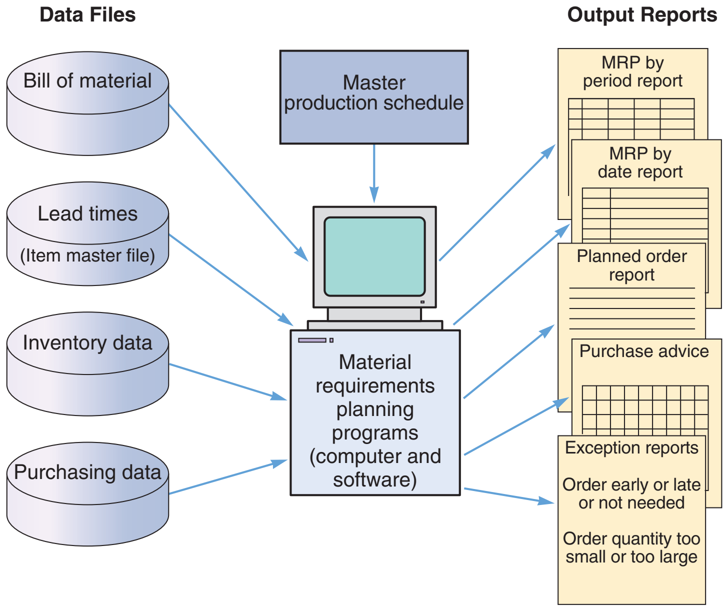


Figure 14.4

Structure of the MRP System

STUDENT TIP

MRP software programs are popular because manual approaches are slow and error prone.

Example 2

BUILDING A GROSS REQUIREMENTS PLAN

Each Awesome speaker kit (item A of Example 1) requires all the items in the product structure for A. Lead times are shown in Table 14.2.

APPROACH ▶ Using the information in Example 1 and Table 14.2, we construct the gross material requirements plan with a production schedule that will satisfy the demand of 50 units of A by week 8.

SOLUTION ▶ We prepare a schedule as shown in Table 14.3.

TABLE 14.3 **Gross Material Requirements Plan for 50 Awesome Speaker Kits (As) with Order Release Dates Also Shown**

	WEEK								
	1	2	3	4	5	6	7	8	LEAD TIME
A. Required date								50	
Order release date							50		1 week
B. Required date							100		
Order release date					100				2 weeks
C. Required date							150		
Order release date						150			1 week
E. Required date					200	300			
Order release date			200	300					2 weeks
F. Required date						300			
Order release date			300						3 weeks
D. Required date			600		200				
Order release date		600		200					1 week
G. Required date			300						
Order release date	300								2 weeks

LO 14.2 *Build* a gross requirements plan

You can interpret the gross material requirements shown in Table 14.3 as follows: If you want 50 units of A at week 8, you must start assembling A in week 7. Thus, in week 7, you will need 100 units of B and 150 units of C. These two items take 2 weeks and 1 week, respectively, to produce. Production of B, therefore, should start in week 5, and production of C should start in week 6 (lead time subtracted from the required date for these items). Working backward, we can perform the same computations for all of the other items. Because D and E are used in two different places in Awesome speaker kits, there are two entries in each data record.

INSIGHT ▶ The gross material requirements plan shows when production of each item should begin and end in order to have 50 units of A at week 8. Management now has an initial plan.

LEARNING EXERCISE ▶ If the lead time for G decreases from 2 weeks to 1 week, what is the new order release date for G? [Answer: 300 in week 2.]

RELATED PROBLEMS ▶ 14.6, 14.8, 14.10a, 14.11a

EXCEL OM Data File **Ch14Ex2.xls** can be found in MyOMLab.

Net requirements plan
The result of adjusting gross requirements for inventory on hand and scheduled receipts.

So far, we have considered *gross material requirements*, which assumes that there is no inventory on hand. A **net requirements plan** adjusts for on-hand inventory. When considering on-hand inventory, we must realize that many items in inventory contain subassemblies or parts. If the gross requirement for Awesome speaker kits (As) is 100 and there are 20 of those speakers on hand, the net requirement for As is 80 (that is, 100 – 20). However, each Awesome speaker kit on hand contains 2 Bs. As a result, the requirement for Bs drops by 40 Bs (20 A kits on hand × 2 Bs per A). Therefore, if inventory is on hand for a parent item, the requirements for the parent item and all its components decrease because each Awesome kit contains the components for lower-level items. Example 3 shows how to create a net requirements plan.

Example 3

LO 14.3 *Build* a net requirements plan

DETERMINING NET REQUIREMENTS

Speaker Kits, Inc., developed a product structure from a bill of material in Example 1. Example 2 developed a gross requirements plan. Given the following on-hand inventory, Speaker Kits, Inc., now wants to construct a net requirements plan. The gross requirement remains 50 units in week 8, and component requirements are as shown in the product structure in Example 1.

ITEM	ON HAND	ITEM	ON HAND
A	10	E	10
B	15	F	5
C	20	G	0
D	10		

Net Material Requirements Plan for 50 Units of Product A in Week 8. ***(The superscript is the source of the demand)***

Lot Size	Lead Time (weeks)	On Hand	Safety Stock	Allo-cated	Low-Level Code	Item Identi-fication			Week 1	2	3	4	5	6	7	8
Lot-for-Lot	1	10	—	—	0	A	Gross Requirements									50
							Scheduled Receipts									
							Projected On Hand	10	10	10	10	10	10	10	10	10
							Net Requirements									40
							Planned Order Receipts									40
							Planned Order Releases								40	
Lot-for-Lot	2	15	—	—	1	B	Gross Requirements								80^A	
							Scheduled Receipts									
			2 × number of As = 80				Projected On Hand	15	15	15	15	15	15	15	15	
							Net Requirements								65	
							Planned Order Receipts								65	
							Planned Order Releases						65			
Lot-for-Lot	1	20	—	—	1	C	Gross Requirements								120^A	
							Scheduled Receipts									
			3 × number of As = 120				Projected On Hand	20	20	20	20	20	20	20	20	
							Net Requirements								100	
							Planned Order Receipts								100	
							Planned Order Releases							100		
Lot-for-Lot	2	10	—	—	2	E	Gross Requirements						130^B	200^C		
							Scheduled Receipts									
			2 × number of Bs = 130 2 × number of Cs = 200				Projected On Hand	10	10	10	10	10	10			
							Net Requirements						120	200		
							Planned Order Receipts						120	200		
							Planned Order Releases				120	200				
Lot-for-Lot	3	5	—	—	2	F	Gross Requirements							200^C		
							Scheduled Receipts									
			2 × number of Cs = 200				Projected On Hand	5	5	5	5	5	5	5		
							Net Requirements							195		
							Planned Order Receipts							195		
							Planned Order Releases				195					
Lot-for-Lot	1	10	—	—	3	D	Gross Requirements				390^F		130^B			
							Scheduled Receipts									
			2 × number of Bs = 130 2 × number of Fs = 390				Projected On Hand	10	10	10	10					
							Net Requirements				380		130			
							Planned Order Receipts				380		130			
							Planned Order Releases			380		130				
Lot-for-Lot	2	0	—	—	3	G	Gross Requirements				195^F					
							Scheduled Receipts									
			1 × number of Fs = 195				Projected On Hand				0					
							Net Requirements				195					
							Planned Order Receipts				195					
							Planned Order Releases		195							

APPROACH ▶ A net material requirements plan includes gross requirements, on-hand inventory, net requirements, planned order receipt, and planned order release for each item. We begin with A and work backward through the components.

SOLUTION ▶ Shown in the MRP format on the previous page is the net material requirements plan for product A.

Constructing a net requirements plan is similar to constructing a gross requirements plan. Starting with item A, we work backward to determine net requirements for all items. To do these computations, we refer to the product structure, on-hand inventory, and lead times. The gross requirement for A is 50 units in week 8. Ten items are on hand; therefore, the net requirements and the scheduled **planned order receipt** are both 40 items in week 8. Because of the one-week lead time, the **planned order release** is 40 items in week 7 (see the arrow connecting the order receipt and order release). Referring to week 7 and the product structure in Example 1, we can see that 80 (2×40) items of B and 120 (3×40) items of C are required in week 7 to have a total for 50 items of A in week 8. The letter superscripted A to the right of the gross figure for items B and C was generated as a result of the demand for the parent, A. Performing the same type of analysis for B and C yields the net requirements for D, E, F, and G. Note the on-hand inventory in row E in week 6 is zero. It is zero because the on-hand inventory (10 units) was used to make B in week 5. By the same token, the inventory for D was used to make F in week 3.

Planned order receipt
The quantity planned to be received at a future date.

Planned order release
The scheduled date for an order to be released.

INSIGHT ▶ Once a net requirement plan is completed, management knows the quantities needed, an ordering schedule, and a production schedule for each component.

LEARNING EXERCISE ▶ If the on-hand inventory quantity of component F is 95 rather than 5, how many units of G will need to be ordered in week 1? [Answer: 105 units.]

RELATED PROBLEMS ▶ 14.9, 14.10b, 14.11b, 14.12, 14.13c, 14.14b, 14.15a,b,c, 14.16a,b, 14.17c (14.18–14.21 are available in MyOMLab)

ACTIVE MODEL 14.1 This example is further illustrated in Active Model 14.1 in MyOMLab.

EXCEL OM Data File **Ch14Ex3.xls** can be found in MyOMLab.

STUDENT TIP MRP gross requirements can combine multiple products, spare parts, and items sold directly.

Examples 2 and 3 considered only product A, the Awesome speaker kit, and its completion only in week 8. Fifty units of A were required in week 8. Normally, however, there is a demand for many products over time. For each product, management must prepare a master production schedule (as we saw earlier, in Table 14.1). Scheduled production of each product is added to the master schedule and ultimately to the net material requirements plan. Figure 14.5 shows how several product schedules, including requirements for components sold directly, can contribute to one gross material requirements plan.

Most inventory systems also note the number of units in inventory that have been assigned to specific future production but not yet used or issued from the stockroom. Such items are often

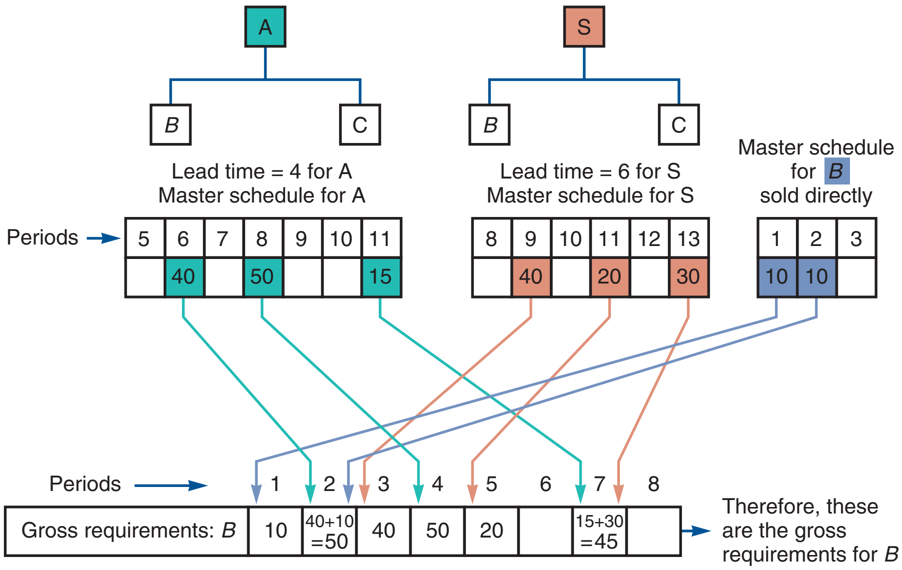


Figure 14.5

Several Schedules Contributing to a Gross Requirements Schedule for B

One B is in each A, and one B is in each S; in addition, 10 Bs sold directly are scheduled in week 1, and 10 more that are sold directly are scheduled in week 2.

Lot Size	Lead Time	On Hand	Safety Stock	Allocated	Low-Level Code	Item ID			Period 1	2	3	4	5	6	7	8
Lot FoR Lot	1	0	0	10	0	Z	Gross Requirements									~~80~~ 90
							Scheduled Receipts									0
							Projected On Hand	0	0	0	0	0	0	0	0	0
							Net Requirements									90
							Planned Order Receipts									90
							Planned Order Releases								90	

Figure **14.6**

Sample MRP Planning Sheet for Item Z

referred to as *allocated* items. Allocated items increase requirements as shown in Figure 14.6, where gross requirements have been increased from 80 to 90 to reflect the 10 allocated items.

Safety Stock The continuing task of operations managers is to remove variability. This is the case in MRP systems as in other operations systems. Realistically, however, managers need to realize that bills of material and inventory records, like purchase and production quantities, as well as lead times, may not be perfect. This means that some consideration of safety stock may be prudent. Because of the significant domino effect of any change in requirements, safety stock should be minimized, with a goal of ultimate elimination. When safety stock is deemed absolutely necessary, the usual policy is to build it into (increase) the inventory requirement of the MRP logic. Distortion can be minimized when safety stock is held at the finished goods or module level and at the purchased component or raw material level.

MRP Management

Now let's look at the dynamics and limitations of MRP.

MRP Dynamics

The inputs to MRP (the master schedule, BOM, lead times, purchasing, and inventory) frequently change. Conveniently, a central strength of MRP systems is timely and accurate replanning. However, many firms find they do not want to respond to minor scheduling or quantity changes even if they are aware of them. These frequent changes generate what is called **system nervousness** and can create havoc in purchasing and production departments if implemented. Consequently, OM personnel reduce such nervousness by evaluating the need and impact of changes prior to disseminating requests to other departments. Two tools are particularly helpful when trying to reduce MRP system nervousness.

The first is time fences. **Time fences** allow a segment of the master schedule to be designated as "not to be rescheduled." This segment of the master schedule is therefore not changed during the periodic regeneration of schedules. The second tool is pegging. **Pegging** means tracing upward in the BOM from the component to the parent item. By pegging upward, the production planner can determine the cause for the requirement and make a judgment about the necessity for a change in the schedule.

With MRP, the operations manager *can* react to the dynamics of the real world. If the nervousness is caused by legitimate changes, then the proper response may be to investigate the production environment—not adjust via MRP.

System nervousness
Frequent changes in an MRP system.

Time fences
A means for allowing a segment of the master schedule to be designated as "not to be rescheduled."

Pegging
In material requirements planning systems, tracing upward the bill of material from the component to the parent item.

MRP Limitations

MRP does not do detailed scheduling—it plans. MRP is an excellent tool for product-focused and repetitive facilities, but it has limitations in process (make-to-order) environments. MRP will tell you that a job needs to be completed on a certain week or day but does not tell you

Buckets
Time units in a material requirements planning system.

that Job X needs to run on Machine A at 10:30 A.M. and be completed by 11:30 A.M. so that Job X can then run on Machine B. MRP is also a planning technique with *fixed* lead times that loads work into *infinite* size "buckets." The **buckets** are time units, usually one week. MRP puts work into these buckets without regard to capacity. Consequently, MRP is considered an *infinite* scheduling technique. Techniques for the alternative, *finite* scheduling, are discussed in Chapter 15.

Lot-Sizing Techniques

Lot-sizing decision
The process of, or techniques used in, determining lot size.

Lot-for-lot
A lot-sizing technique that generates exactly what is required to meet the plan.

An MRP system is an excellent way to do production planning and determine net requirements. But net requirements still demand a decision about *how much and when* to order. This decision is called a **lot-sizing decision**. There are a variety of ways to determine lot sizes in an MRP system; commercial MRP software usually includes the choice of several lot-sizing techniques. We now review a few of them.

Lot-for-Lot In Example 3, we used a lot-sizing technique known as **lot-for-lot**, which produced exactly what was required. This decision is consistent with the objective of an MRP system, which is to meet the requirements of *dependent* demand. Thus, an MRP system should produce units only as needed, with no safety stock and no anticipation of further orders. When frequent orders are economical (i.e., when setup costs are low) and just-in-time inventory techniques implemented, lot-for-lot can be very efficient. However, when setup costs are significant, lot-for-lot can be expensive. Example 4 uses the lot-for-lot criteria and determines cost for 10 weeks of demand.

Example 4

LOT SIZING WITH LOT-FOR-LOT

Speaker Kits, Inc., wants to compute its ordering and carrying cost of inventory on lot-for-lot criteria.

APPROACH ▶ With lot-for-lot, we order material only as it is needed. Once we have the cost of ordering (setting up), the cost of holding each unit for a given time period, and the production schedule, we can assign orders to our net requirements plan.

SOLUTION ▶ Speaker Kits has determined that, for **component B,** setup cost is $100 and holding cost is $1 per period. The production schedule, as reflected in net requirements for assemblies, is as follows:

MRP Lot Sizing: Lot-for-Lot Technique*

WEEK		1	2	3	4	5	6	7	8	9	10
Gross requirements		35	30	40	0	10	40	30	0	30	55
Scheduled receipts											
Projected on hand	35	35	0	0	0	0	0	0	0	0	0
Net requirements		0	30	40	0	10	40	30	0	30	55
Planned order receipts			30	40		10	40	30		30	55
Planned order releases		30	40		10	40	30		30	55	

*Holding costs = $1/unit/week; setup cost = $100; gross requirements average per week = 27; lead time = 1 week.

The lot-sizing solution using the lot-for-lot technique is shown in the table. The holding cost is zero as there is never any end-of-period inventory. (Inventory in the first period is used immediately and therefore has no holding cost.) But seven separate setups (one associated with each order) yield a total cost of $700. (Holding cost $= 0 \times 1 = 0$; ordering cost $= 7 \times 100 = 700$.)

INSIGHT ▶ When supply is reliable and frequent orders are inexpensive, but holding cost or obsolescence is high, lot-for-lot ordering can be very efficient.

LEARNING EXERCISE ▶ What is the impact on total cost if holding cost is $2 per period rather than $1? [Answer: Total holding cost remains zero, as no units are held from one period to the next with lot-for-lot.]

RELATED PROBLEMS ▶ 14.22, 14.25, 14.26a, 14.27a (14.28b is available in MyOMLab)

John Russell/AP Images

This Nissan line in Smyrna, Tennessee, has little inventory because Nissan schedules to a razor's edge. At Nissan, MRP helps reduce inventory to world-class standards. World-class automobile assembly requires that purchased parts have a turnover of slightly more than once a day and that overall turnover approaches 150 times per year.

Economic Order Quantity (EOQ) We now extend our discussion of EOQ in Chapter 12 to use it as a lot-sizing technique for MRP systems. As we indicated there, EOQ is useful when we have relatively constant demand. However, demand may change every period in MRP systems. Therefore, EOQ lot sizing often does not perform well in MRP. Operations managers should take advantage of demand information when it is known, rather than assuming a constant demand. EOQ is used to do lot sizing in Example 5 for comparison purposes.

LO 14.4 *Determine* lot sizes for lot-for-lot, EOQ, and POQ

Example 5

LOT SIZING WITH EOQ

With a setup cost of \$100 and a holding cost per week of \$1, Speaker Kits, Inc., wants to examine its cost for **component B,** with lot sizes based on an EOQ criteria.

APPROACH ▶ Using the same cost and production schedule as in Example 4, we determine net requirements and EOQ lot sizes.

SOLUTION ▶ Ten-week usage equals a gross requirement of 270 units; therefore, weekly usage equals 27, and 52 weeks (annual usage) equals 1,404 units. From Chapter 12, the EOQ model is:

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

where D = annual usage = 1,404

S = setup cost = \$100

H = holding (carrying) cost, on an annual basis per unit

= \$1 × 52 weeks = \$52

$$Q^* = 73 \text{ units}$$

Therefore, place an order of 73 units, as necessary, to avoid a stockout.

MRP Lot Sizing: EOQ Technique*

WEEK		1	2	3	4	5	6	7	8	9	10
Gross requirements		35	30	40	0	10	40	30	0	30	55
Scheduled receipts											
Projected on hand	35	35	0	43	3	3	66	26	69	69	39
Net requirements		0	30	0	0	7	0	4	0	0	16
Planned order receipts			73			73		73			73
Planned order releases		73			73		73			73	

*Holding costs = $1/unit/week; setup cost = $100; gross requirements average per week = 27; lead time = 1 week.

For the 10-week planning period:

Holding cost = 375 units × $1 = $375 (includes 57 remaining at the end of week 10)

Ordering cost = 4 × $100 = $400

Total = $375 + $400 = $775

INSIGHT ▶ EOQ can be a reasonable lot-sizing technique when demand is relatively constant. However, notice that actual holding cost will vary substantially depending on the rate of actual usage. If any stockouts had occurred, these costs too would need to be added to our actual EOQ cost of $775.

LEARNING EXERCISE ▶ What is the impact on total cost if holding cost is $2 per period rather than $1? [Answer: The EOQ quantity becomes 52, the theoretical annual total cost becomes $5,404, and the 10-week cost is $1,039 ($5,404 × (10/52).]

RELATED PROBLEMS ▶ 14.23, 14.25, 14.26b, 14.27c (14.28a is available in MyOMLab)

Periodic order quantity (POQ)
An inventory ordering technique that issues orders on a predetermined time interval, with the order quantity covering the total of the interval's requirements.

Periodic Order Quantity Periodic order quantity (POQ) is a lot-sizing technique that orders the quantity needed during a predetermined time between orders, such as every 3 weeks. We define the *POQ interval* as the EOQ divided by the average demand per period (e.g., one week).[3] The POQ is the order quantity that covers the specific demand for that interval. *Each order quantity is recalculated at the time of the order release*, never leaving extra inventory. An application of POQ is shown in Example 6.

Example 6

LOT SIZING WITH POQ

With a setup cost of $100 and a holding cost per week of $1, Speaker Kits, Inc., wants to examine its cost for **component B,** with lot sizes based on POQ.

APPROACH ▶ Using the same cost and production schedule as in Example 5, we determine net requirements and POQ lot sizes.

SOLUTION ▶ Ten-week usage equals a gross requirement of 270 units; therefore, average weekly usage equals 27, and from Example 5, we know the EOQ is 73 units.

We set the *POQ interval* equal to the EOQ divided by the average weekly usage.

Therefore:

$$\text{POQ interval} = \text{EOQ/Average weekly usage} = 73/27 = 2.7, \text{ or } 3 \text{ weeks.}$$

The *POQ order size* will vary by the quantities required in the respective weeks, as shown in the following table, with first planned order release in week 1.

Note: Orders are postponed if no demand exists, which is why week 7's order is postponed until week 8.

MRP Lot Sizing: POQ Technique*

WEEK		1	2	3	4	5	6	7	8	9	10
Gross requirements		35	30	40	0	10	40	30	0	30	55
Scheduled receipts											
Projected on hand	35	35	0	40	0	0	70	30	0	0	55
Net requirements		0	30	0	0	10	0	0	0	55	0
Planned order receipts			70			80		0		85	0
Planned order releases		70			80				85		

*Holding costs = $1/unit/week; setup cost = $100; gross requirements average per week = 27; lead time = 1 week.

$$\text{Setups} = 3 \times \$100 = \$300$$

$$\text{Holding cost} = (40 + 70 + 30 + 55) \text{ units} \times \$1 \text{ each} = \$195$$

$$\text{The POQ solution yields a computed 10-week cost of } \$300 + \$195 = \$495$$

INSIGHT ▶ Because POQ tends to produce a balance between holding and ordering costs with no excess inventory, POQ typically performs much better than EOQ. Notice that even with frequent recalculations, actual holding cost can vary substantially, depending on the demand fluctuations. We are assuming no stockouts. In this and similar examples, we are also assuming no safety stock; such costs would need to be added to our actual cost.

LEARNING EXERCISE ▶ What is the impact on total cost if holding cost is $2 per period rather than $1? [Answer: EOQ = 52; POQ interval = 52/27 = 1.93 ≈ 2 weeks; holding cost = $270; setups = $400. The POQ total cost becomes $670.]

RELATED PROBLEMS ▶ 14.24, 14.25, 14.26c, 14.27b (14.28c is available in MyOMLab)

Other lot-sizing techniques, known as *dynamic lot-sizing*, are similar to periodic order quantity as they attempt to balance the lot size against the setup cost. These are *part period balancing* (also called *least total cost*), *least unit cost,* and *least period cost* (also called *Silver-Meal*). Another technique, *Wagner-Whitin*, takes a different approach by using dynamic programming to optimize ordering over a finite time horizon.[4]

Lot-Sizing Summary In the three speaker kits lot-sizing examples, we found the following costs:

	COSTS		
	SETUP	HOLDING	TOTAL
Lot-for-lot	$700	$0	$700
Economic order quantity (EOQ)	$400	$375	$775
Periodic order quantity (POQ)	$300	$195	$495

These examples should not, however, lead operations personnel to hasty conclusions about the preferred lot-sizing technique. In theory, new lot sizes should be computed whenever there is a schedule or lot-size change anywhere in the MRP hierarchy. In practice, such changes cause the instability and system nervousness referred to earlier in this chapter. Consequently, such frequent changes are not made. This means that all lot sizes are wrong because the production system cannot and should not respond to frequent changes. Note that there are no "shortage" (out of stock) charges in any of these lot-sizing techniques. This limitation places added demands on accurate forecasts and "time fences."

In general, the lot-for-lot approach should be used whenever low-cost setup can be achieved. Lot-for-lot is the goal. Lots can be modified as necessary for scrap allowances, process constraints (for example, a heat-treating process may require a lot of a given size), or raw material purchase lots (for example, a truckload of chemicals may be available in only one lot size). However, caution should be exercised prior to any modification of lot size because the modification can cause substantial distortion of actual requirements at lower levels in the MRP hierarchy. When setup costs are significant and demand is reasonably smooth, POQ or even EOQ should provide satisfactory results. Too much concern with lot sizing yields false accuracy because of MRP dynamics. A correct lot size can be determined only after the fact, based on what actually happened in terms of requirements.

Extensions of MRP

In this section, we review three extensions of MRP.

Material Requirements Planning II (MRP II)

Material requirements planning II (MRP II)
A system that allows, with MRP in place, inventory data to be augmented by other resource variables; in this case, MRP becomes *material resource planning.*

LO 14.5 *Describe* MRP II

Material requirements planning II is an extremely powerful technique. Once a firm has MRP in place, requirements data can be enriched by resources other than just components. When MRP is used this way, *resource* is usually substituted for *requirements*, and MRP becomes **MRP II**. It then stands for material resource planning.

So far in our discussion of MRP, we have scheduled products and their components. However, products require many resources, such as energy and money, beyond the product's tangible components. In addition to these resource inputs, *outputs* can be generated as well. Outputs can include such things as scrap, packaging waste, effluent, and carbon emissions. As OM becomes increasingly sensitive to environmental and sustainability issues, identifying and managing by-products takes on more significance. MRP II provides a vehicle for doing so. Table 14.4 provides an example of labor-hours, machine-hours, grams of greenhouse gas emissions, pounds of scrap, and cash, in the format of a gross requirements plan. With MRP II, management can identify both the inputs and outputs as well as the relevant schedule. MRP II provides another tool in OM's battle for sustainable operations.

Jim Convis, User Solutions, Inc.

Many MRP programs, such as *Resource Manager for Excel*, are commercially available. *Resource Manager's* initial menu screen is shown here.

A demo program is available for student use at **www.usersolutions.com.**

TABLE 14.4 Material Resource Planning (MRP II)

		Weeks			
	LEAD TIME	5	6	7	8
Computer *Labor-hours:* .2 each *Machine-hours:* .2 each *GHG Emissions:* .25 each *Scrap:* 1 ounce fiberglass each *Payables:* $0	1				100 20 20 25 grams 6.25 lb $0
PC board (1 each) *Labor-hours:* .15 each *Machine-hours:* .1 each *GHG Emissions:* 2.5 each *Scrap:* .5 ounces copper each *Payables:* raw material at $5 each	2			100 15 10 250 grams 3.125 lb $500	
Processors (5 each) *Labor-hours:* .2 each *Machine-hours:* .2 each *GHG Emissions:* .50 each *Scrap:* .01 ounces of acid waste each *Payables:* processor components at $10 each	4	500 100 100 25,000 grams 0.3125 lb $5,000			

By utilizing the logic of MRP, resources such as labor, machine-hours, greenhouse gas emissions, scrap, and cost can be accurately determined and scheduled. Weekly demand for labor, machine-hours, greenhouse gas emissions, scrap, and payables for 100 computers are shown.

MRP II systems are seldom stand-alone programs. Most are tied into other computer software. Purchasing, production scheduling, capacity planning, inventory, and warehouse management systems are a few examples of this data integration.

Closed-Loop MRP

Closed-loop material requirements planning implies an MRP system that provides feedback to scheduling from the inventory control system. Specifically, a **closed-loop MRP system** provides information to the capacity plan, master production schedule, and ultimately to the production plan (as shown in Figure 14.7). Virtually all commercial MRP systems are closed-loop.

Closed-loop MRP system
A system that provides feedback to the capacity plan, master production schedule, and production plan so planning can be kept valid at all times.

Capacity Planning

In keeping with the definition of closed-loop MRP, feedback about workload is obtained from each work center. **Load reports** show the resource requirements in a work center for all work currently assigned to the work center, all work planned, and expected orders.

Load report
A report showing the resource requirements in a work center for all work currently assigned there as well as all planned and expected orders.

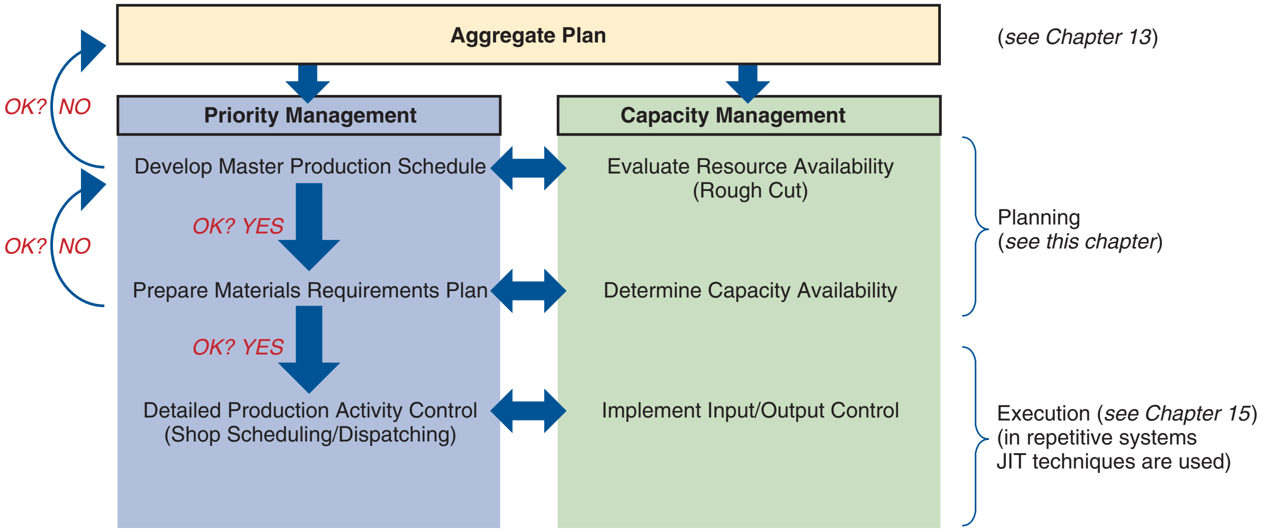


Figure 14.7

Closed-Loop Material Requirements Planning

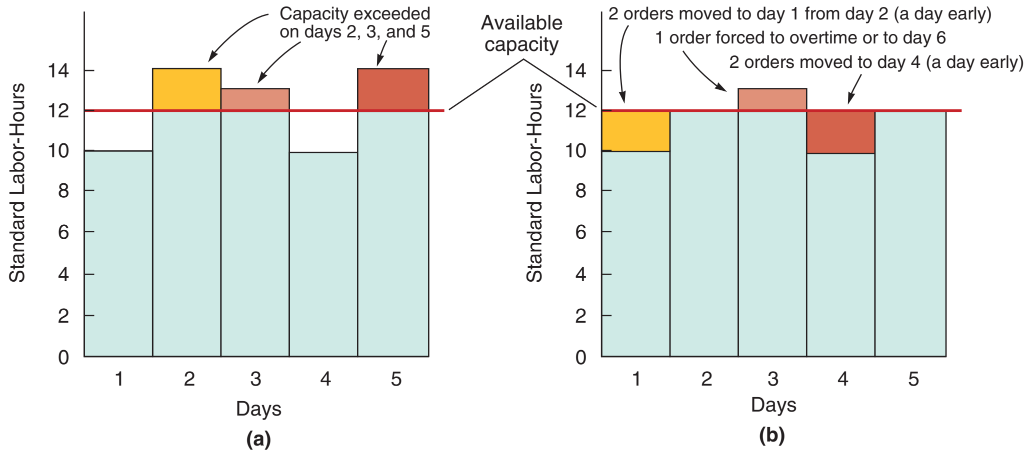


Figure 14.8

(a) Initial Resource Requirements Profile for a Work Center
(b) Smoothed Resource Requirements Profile for a Work Center

LO 14.6 *Describe* closed-loop MRP

Figure 14.8(a) shows that the initial load in the milling center exceeds capacity on days 2, 3, and 5. Closed-loop MRP systems allow production planners to move the work between time periods to smooth the load or at least bring it within capacity. (This is the "capacity planning" part of Figure 14.7.) The closed-loop MRP system can then reschedule all items in the net requirements plan (see Figure 14.8[b]).

Tactics for smoothing the load and minimizing the impact of changed lead time include the following:

1. *Overlapping,* which reduces the lead time, sends pieces to the second operation before the entire lot is completed on the first operation.
2. *Operations splitting* sends the lot to two different machines for the same operation. This involves an additional setup, but results in shorter throughput times because only part of the lot is processed on each machine.
3. *Order splitting,* or *lot splitting*, involves breaking up the order and running part of it earlier (or later) in the schedule.

Example 7 shows a brief detailed capacity scheduling example using order splitting to improve utilization.

Example 7

ORDER SPLITTING

Kevin Watson, the production planner at Wiz Products, needs to develop a capacity plan for a work center. He has the production orders shown below for the next 5 days. There are 12 hours available in the work cell each day. The parts being produced require 1 hour each.

Day	1	2	3	4	5
Orders	10	14	13	10	14

APPROACH ▶ Compute the time available in the work center and the time necessary to complete the production requirements.

SOLUTION ▶

DAY	UNITS ORDERED	CAPACITY REQUIRED (HOURS)	CAPACITY AVAILABLE (HOURS)	UTILIZATION: OVER/ (UNDER) (HOURS)	PRODUCTION PLANNER'S ACTION	NEW PRODUCTION SCHEDULE
1	10	10	12	(2)		12
2	14	14	12	2	Split order: move 2 units to day 1	12
3	13	13	12	1	Split order: move 1 unit to day 6 or request overtime	13
4	10	10	12	(2)		12
5	14	14	12	2	Split order: move 2 units to day 4	12
	61					

INSIGHT ▶ By moving orders, the production planner is able to utilize capacity more effectively and still meet the order requirements, with only 1 order produced on overtime in day 3.

LEARNING EXERCISE ▶ If the units ordered for day 5 increase to 16, what are the production planner's options? [Answer: In addition to moving 2 units to day 4, move 2 units of production to day 6, or request overtime.]

RELATED PROBLEMS ▶ 14.29, 14.30

When the workload consistently exceeds work-center capacity, the tactics just discussed are not adequate. This may mean adding capacity via personnel, machinery, overtime, or subcontracting.

MRP in Services

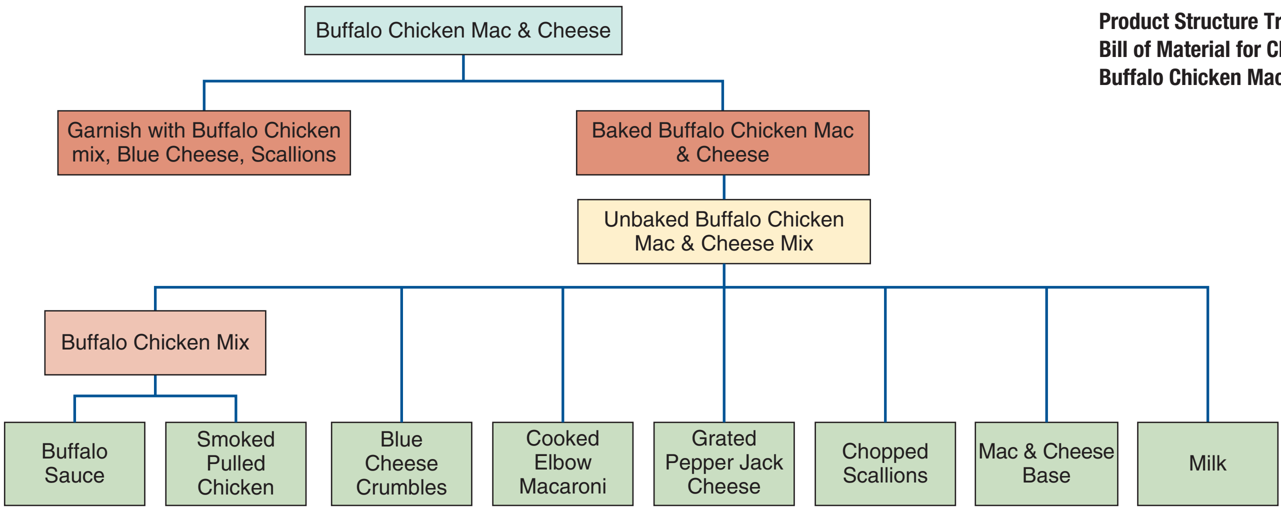
The demand for many services or service items is classified as dependent demand when it is directly related to or derived from the demand for other services. Such services often require product-structure trees, bills of material and labor, and scheduling. Variations of MRP systems can make a major contribution to operational performance in such services. Examples from restaurants, hospitals, and hotels follow.

Restaurants In restaurants, ingredients and side dishes (bread, vegetables, and condiments) are typically meal components. These components are dependent on the demand for meals. The meal is an end item in the master schedule. Figure 14.9 shows (a) a product-structure tree and

Figure 14.9

Product Structure Tree and Bill of Material for Chef John's Buffalo Chicken Mac & Cheese

(a) PRODUCT STRUCTURE TREE



(b) BILL OF MATERIALS

Production Specification	**Buffalo Chicken Mac & Cheese (6 portions)**				
Ingredients	*Quantity*	*Measure*	*Unit Cost*	*Total Cost*	*Labor Hrs.*
Elbow Macaroni (large, uncooked)	20.00	oz.	$ 0.09	$ 1.80	
Cheese—Pepper Jack (grated)	10.00	oz.	0.17	1.70	
Mac and Cheese Base (from refrigerator)	32.00	oz.	0.80	25.60	
Milk	4.00	oz.	0.03	0.12	
Smoked Pulled Chicken	2.00	lb.	2.90	5.80	
Buffalo Sauce	8.00	oz.	0.09	0.72	
Blue Cheese Crumbles	4.00	oz.	0.19	0.76	
Scallions	2.00	oz.	0.18	0.36	
Total Labor Hours					0.2 hrs

(b) bill of material (here called a *product specification*) for 6 portions of *Buffalo Chicken Mac & Cheese,* a popular dish prepared by Chef John for Orlando Magic fans at the Amway Center.

Hospitals MRP is also applied in hospitals, especially when dealing with surgeries that require known equipment, materials, and supplies. Houston's Park Plaza Hospital and many hospital suppliers, for example, use the technique to improve the scheduling and management of expensive surgical inventory.

Hotels Marriott develops a bill of material and a bill of labor when it renovates each of its hotel rooms. Marriott managers explode the BOM to compute requirements for materials, furniture, and decorations. MRP then provides net requirements and a schedule for use by purchasing and contractors.

Distribution Resource Planning (DRP)

When dependent techniques are used in the supply chain, they are called distribution resource planning (DRP). **Distribution resource planning (DRP)** is a time-phased stock-replenishment plan for all levels of the supply chain.

Distribution resource planning (DRP)
A time-phased stock-replenishment plan for all levels of a distribution network.

DRP procedures and logic are analogous to MRP. With DRP, expected demand becomes gross requirements. Net requirements are determined by allocating available inventory to gross requirements. The DRP procedure starts with the forecast at the retail level (or the most distant point of the distribution network being supplied). All other levels are computed. As is the case with MRP, inventory is then reviewed with an aim to satisfying demand. So that stock will arrive when it is needed, net requirements are offset by the necessary lead time. A planned order release quantity becomes the gross requirement at the next level down the distribution chain.

DRP *pulls* inventory through the system. Pulls are initiated when the retail level orders more stock. Allocations are made to the retail level from available inventory and production after being adjusted to obtain shipping economies. Effective use of DRP requires an integrated information system to rapidly convey planned order releases from one level to the next. The goal of the DRP system is small and frequent replenishment within the bounds of economical ordering and shipping.

Enterprise Resource Planning (ERP)

Advances in MRP II systems that tie customers and suppliers to MRP II have led to the development of enterprise resource planning (ERP) systems. **Enterprise resource planning (ERP)** is software that allows companies to (1) automate and integrate many of their business processes, (2) share a common database and business practices throughout the enterprise, and (3) produce information in real time. A schematic showing some of these relationships for a manufacturing firm appears in Figure 14.10.

Enterprise resource planning (ERP)
An information system for identifying and planning the enterprise-wide resources needed to take, make, ship, and account for customer orders.

The objective of an ERP system is to coordinate a firm's entire business, from supplier evaluation to customer invoicing. This objective is seldom achieved, but ERP systems are umbrella systems that tie together a variety of specialized systems. This is accomplished by using a centralized database to assist the flow of information among business functions. Exactly what is tied together, and how, varies on a case-by-case basis. In addition to the traditional components of MRP, ERP systems usually provide financial and human resource (HR) management information. ERP systems may also include:

LO 14.7 *Describe* ERP

- *Supply-chain management (SCM)* software to support sophisticated vendor communication, e-commerce, and those activities necessary for efficient warehousing and logistics. The idea is to tie operations (MRP) to procurement, to materials management, and to suppliers, providing the tools necessary for effective management of all four areas.
- *Customer relationship management (CRM)* software for the incoming side of the business. CRM is designed to aid analysis of sales, target the most profitable customers, and manage the sales force.
- *Sustainability* software to tie together sustainable workforce issues and provide transparency for supply-chain sustainability issues, as well as monitor health and safety activities, energy use and efficiency, emissions (carbon footprint, greenhouse gases), and environmental compliance.

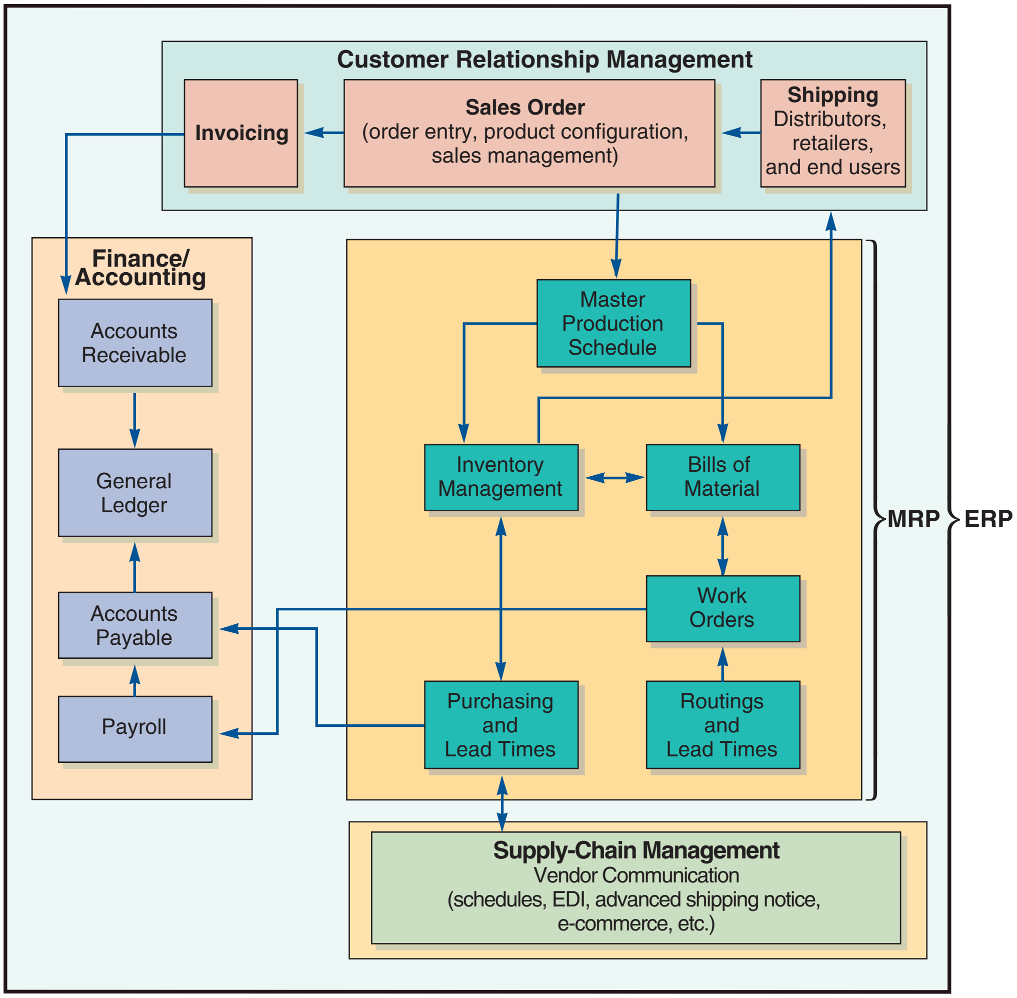


Figure **14.10**

MRP and ERP Information Flows, Showing Customer Relationship Management (CRM), Supply-Chain Management (SCM), and Finance/Accounting

Other functions such as human resources and sustainability are often also included in ERP systems.

STUDENT TIP

ERP tries to integrate all of a firm's information to ensure data integrity.

In addition to data integration, ERP software promises reduced transaction costs and fast, accurate information. A strategic emphasis on just-in-time systems and supply chain integration drives the desire for enterprise-wide software. The *OM in Action* box "Managing Benetton with ERP Software" provides an example of how ERP software helps integrate company operations.

OM in Action — Managing Benetton with ERP Software

Thanks to ERP, the Italian sportswear company Benetton can probably claim to have the world's fastest factory and the most efficient distribution in the garment industry. Located in Ponzano, Italy, Benetton makes and ships 50 million pieces of clothing each year. That is 30,000 boxes every day—boxes that must be filled with exactly the items ordered going to the correct store of the 5,000 Benetton outlets in 60 countries. This highly automated distribution center uses only 19 people. Without ERP, hundreds of people would be needed.

Here is how ERP software works:

1. *Ordering:* A salesperson in the south Boston store finds that she is running out of a best-selling blue sweater. Using a laptop PC, her local Benetton sales agent taps into the ERP sales module.
2. *Availability:* ERP's inventory software simultaneously forwards the order to the mainframe in Italy and finds that half the order can be filled immediately from the Italian warehouse. The rest will be manufactured and shipped in 4 weeks.
3. *Production:* Because the blue sweater was originally created by computer-aided design (CAD), ERP manufacturing software passes the specifications to a knitting machine. The knitting machine makes the sweaters.
4. *Warehousing:* The blue sweaters are boxed with a radio frequency ID (RFID) tag addressed to the Boston store and placed in one of the 300,000 slots in the Italian warehouse. A robot flies by, reading RFID tags, picks out any and all boxes ready for the Boston store, and loads them for shipment.
5. *Order tracking:* The Boston salesperson logs onto the ERP system through the Internet and sees that the sweater (and other items) are completed and being shipped.
6. *Planning:* Based on data from ERP's forecasting and financial modules, Benetton's chief buyer decides that blue sweaters are in high demand and quite profitable. She decides to add three new hues.

Sources: Forbes (December 2, 2011); *The Wall Street Journal* (April 10, 2007); *Information Week* (June 13, 2005); and *MIT Sloan Management Review* (Fall 2001).

In an ERP system, data are entered only once into a common, complete, and consistent database shared by all applications. For example, when a Nike salesperson enters an order into his ERP system for 20,000 pairs of sneakers for Foot Locker, the data are instantly available on the manufacturing floor. Production crews start filling the order if it is not in stock, accounting prints Foot Locker's invoice, and shipping notifies Foot Locker of the future delivery date. The salesperson, or even the customer, can check the progress of the order at any point. This is all accomplished using the same data and common applications. To reach this consistency, however, the data fields must be defined identically across the entire enterprise. In Nike's case, this means integrating operations at production sites from Vietnam to China to Mexico, at business units across the globe, in many currencies, and with reports in a variety of languages.

Each ERP vendor produces unique products. The major vendors, SAP AG (a German firm), BEA (Canada), SSAGlobal, American Software, PeopleSoft/Oracle, and CMS Software (all U.S. firms), sell software or modules designed for specific industries (a set of SAP's modules is shown in Figure 14.11). However, companies must determine if their way of doing business will fit the standard ERP module. If they determine that the product will not fit the standard ERP product, they can change the way they do business to accommodate the software. But such a change can have an adverse impact on their business process, reducing a competitive advantage.

Alternatively, ERP software can be customized to meet their specific process requirements. Although the vendors build the software to keep the customization process simple, many companies spend up to five times the cost of the software to customize it. In addition to the expense, the major downside of customization is that when ERP vendors provide an upgrade or enhancement to the software, the customized part of the code must be rewritten to fit into the new version. ERP programs cost from a minimum of $300,000 for a small company to

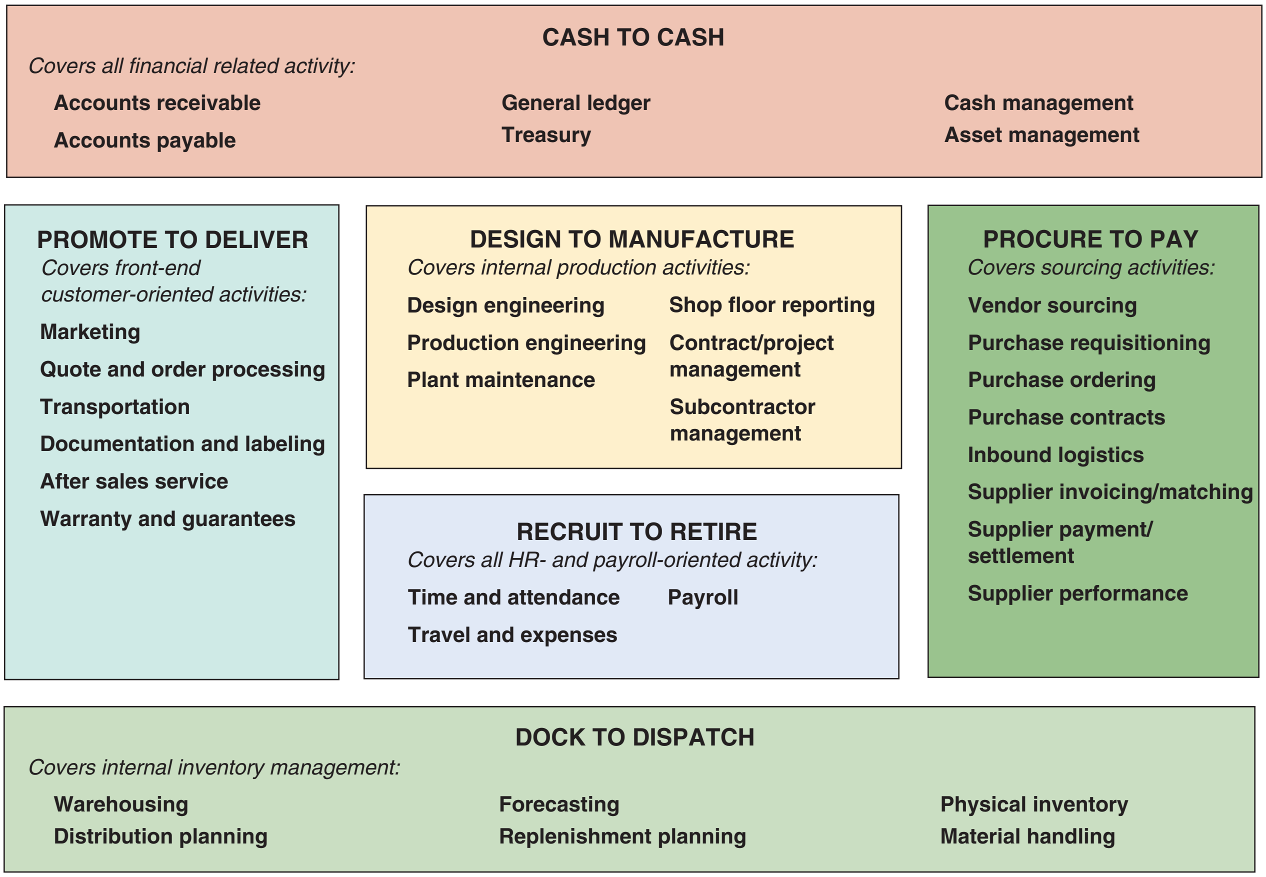


Figure **14.11**

SAP's Modules for ERP

Source: www.sap.com.

hundreds of millions of dollars for global giants like Ford and Coca-Cola. It is easy to see, then, that ERP systems are expensive, full of hidden issues, and time-consuming to install.

ERP in the Service Sector

ERP vendors have developed a series of service modules for such markets as health care, government, retail stores, and financial services. Springer-Miller Systems, for example, has created an ERP package for the hotel market with software that handles all front- and back-office functions. This system integrates tasks such as maintaining guest histories, booking room and dinner reservations, scheduling golf tee times, and managing multiple properties in a chain. PeopleSoft/Oracle combines ERP with supply chain management to coordinate airline meal preparation. In the grocery industry, these supply chain systems are known as *efficient consumer response* (ECR) systems. **Efficient consumer response** systems tie sales to buying, to inventory, to logistics, and to production.

Efficient consumer response (ECR)
Supply chain management systems in the grocery industry that tie sales to buying, to inventory, to logistics, and to production.

Summary

Material requirements planning (MRP) schedules production and inventory when demand is dependent. For MRP to work, management must have a master schedule, precise requirements for all components, accurate inventory and purchasing records, and accurate lead times.

When properly implemented, MRP can contribute in a major way to reduction in inventory while improving customer service levels. MRP techniques allow the operations manager to schedule and replenish stock on a "need-to-order" basis rather than simply a "time-to-order" basis. Many firms using MRP systems find that lot-for-lot can be the low-cost lot-sizing option.

The continuing development of MRP systems has led to its use with lean manufacturing techniques. In addition, MRP can integrate production data with a variety of other activities, including the supply chain and sales. As a result, we now have integrated database-oriented enterprise resource planning (ERP) systems. These expensive and difficult-to-install ERP systems, when successful, support strategies of differentiation, response, and cost leadership.

Key Terms

Material requirements planning (MRP) (p. 604)
Master production schedule (MPS) (p. 605)
Bill of material (BOM) (p. 606)
Modular bills (p. 607)
Planning bills (or kits) (p. 608)
Phantom bills of material (p. 608)
Low-level coding (p. 608)
Lead time (p. 608)
Gross material requirements plan (p. 609)
Net requirements plan (p. 610)
Planned order receipt (p. 612)
Planned order release (p. 612)
System nervousness (p. 613)
Time fences (p. 613)
Pegging (p. 613)
Buckets (p. 614)
Lot-sizing decision (p. 614)
Lot-for-lot (p. 614)
Periodic order quantity (POQ) (p. 616)
Material requirements planning II (MRP II) (p. 618)
Closed-loop MRP system (p. 619)
Load report (p. 619)
Distribution resource planning (DRP) (p. 622)
Enterprise resource planning (ERP) (p. 622)
Efficient consumer response (ECR) (p. 625)

Ethical Dilemma

For many months your prospective ERP customer has been analyzing the hundreds of assumptions built into the $900,000 ERP software you are selling. So far, you have knocked yourself out to try to make this sale. If the sale goes through, you will reach your yearly quota and get a nice bonus. On the other hand, loss of this sale may mean you start looking for other employment.

The accounting, human resource, supply chain, and marketing teams put together by the client have reviewed the specifications and finally recommended purchase of the software. However, as you looked over their shoulders and helped them through the evaluation process, you began to realize that their purchasing procedures—with much of the purchasing being done at hundreds of regional stores—were not a good fit for the software. At the very least, the customizing will add $250,000 to the implementation and training cost. The team is not aware of the issue, and you know that the necessary $250,000 is not in the budget.

What do you do?

Discussion Questions

1. What is the difference between a *gross* requirements plan and a *net* requirements plan?
2. Once a material requirements plan (MRP) has been established, what other managerial applications might be found for the technique?
3. What are the similarities between MRP and DRP?
4. How does MRP II differ from MRP?
5. Which is the best lot-sizing policy for manufacturing organizations?
6. What impact does ignoring carrying cost in the allocation of stock in a DRP system have on lot sizes?
7. MRP is more than an inventory system; what additional capabilities does MRP possess?
8. What are the options for the production planner who has:
   a) scheduled more than capacity in a work center next week?
   b) a consistent lack of capacity in that work center?
9. Master schedules are expressed in three different ways depending on whether the process is continuous, a job shop, or repetitive. What are these three ways?
10. What functions of the firm affect an MRP system? How?
11. What is the rationale for (a) a phantom bill of material, (b) a planning bill of material, and (c) a pseudo bill of material?
12. Identify five specific requirements of an effective MRP system.
13. What are the typical benefits of ERP?
14. What are the distinctions between MRP, DRP, and ERP?
15. As an approach to inventory management, how does MRP differ from the approach taken in Chapter 12, dealing with economic order quantities (EOQ)?
16. What are the disadvantages of ERP?
17. Use the Web or other sources to:
    a) Find stories that highlight the advantages of an ERP system.
    b) Find stories that highlight the difficulties of purchasing, installing, or failure of an ERP system.
18. Use the Web or other sources to identify what an ERP vendor (SAP, PeopleSoft/Oracle, American Software, etc.) includes in these software modules:
    a) Customer relationship management.
    b) Supply-chain management.
    c) Product life cycle management.
19. The structure of MRP systems suggests "buckets" and infinite loading. What is meant by these two terms?

Using Software to Solve MRP Problems

There are many commercial MRP software packages, for companies of all sizes. MRP software for small and medium-size companies includes User Solutions, Inc., a demo of which is available at **www.usersolutions.com,** and MAX, from Exact Software North America, Inc. Software for larger systems is available from SAP, CMS, BEA, Oracle, i2 Technologies, and many others. The Excel OM software that accompanies this text includes an MRP module, as does POM for Windows. The use of both is explained in the following sections.

USING EXCEL OM

Using Excel OM's MRP module requires the careful entry of several pieces of data. The initial MRP screen is where we enter (1) the total number of occurrences of items in the BOM (including the top item), (2) what we want the BOM items to be called (e.g., Item no., Part), (3) total number of periods to be scheduled, and (4) what we want the periods called (e.g., days, weeks).

Excel OM's second MRP screen provides the data entry for an indented bill of material. Here we enter (1) the name of each item in the BOM, (2) the quantity of that item in the assembly, and (3) the correct indent (e.g., parent/child relationship) for each item. The indentations are critical, as they provide the logic for the BOM explosion. The indentations should follow the logic of the product structure tree with indents for each assembly item in that assembly.

Excel OM's third MRP screen repeats the indented BOM and provides the standard MRP tableau for entries. This is shown in Program 14.1 using the data from Examples 1, 2, and 3.

USING POM FOR WINDOWS

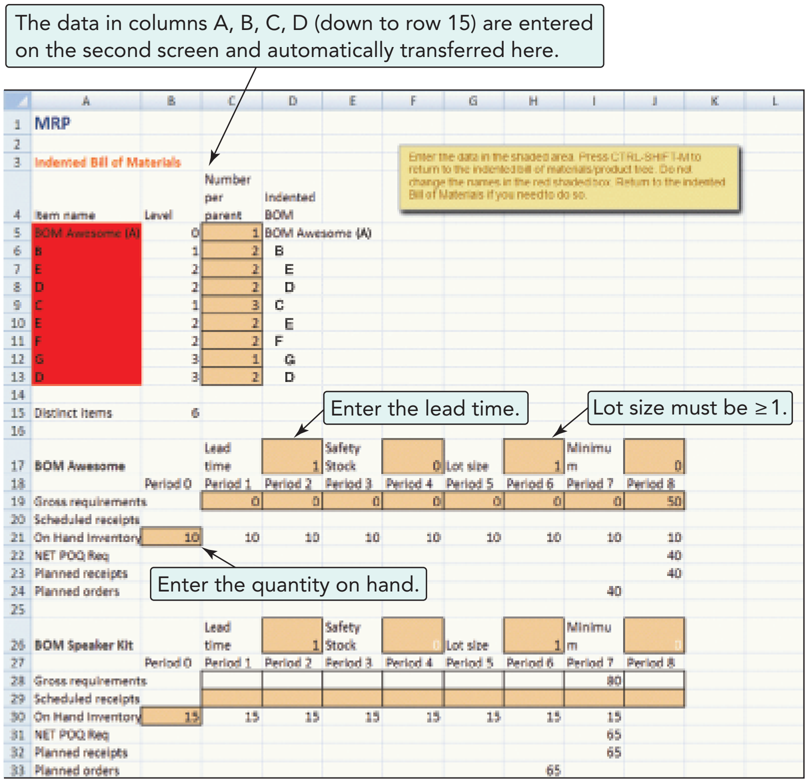
The POM for Windows MRP module can also solve Examples 1 to 3. Up to 18 periods can be analyzed. Here are the inputs required:

1. *Item names:* The item names are entered in the left column. The same item name will appear in more than one row if the item is used by two parent items. Each item must follow its parents.
2. *Item level:* The level in the indented BOM must be given here. The item *cannot* be placed at a level more than one below the item immediately above.
3. *Lead time:* The lead time for an item is entered here. The default is 1 week.
4. *Number per parent:* The number of units of this subassembly needed for its parent is entered here. The default is 1.
5. *On hand:* List current inventory on hand once, even if the subassembly is listed twice.
6. *Lot size:* The lot size can be specified here. A 0 or 1 will perform lot-for-lot ordering. If another number is placed here, then all orders for that item will be in integer multiples of that number.
7. *Demands:* The demands are entered in the end item row in the period in which the items are demanded.
8. *Scheduled receipts:* If units are scheduled to be received in the future, they should be listed in the appropriate time period (column) and item (row). (An entry here in level 1 is a demand; all other levels are receipts.)

Further details regarding POM for Windows are seen in Appendix IV.

Program **14.1**

Using Excel OM's MRP Module to Solve Examples 1, 2, and 3



Solved Problems

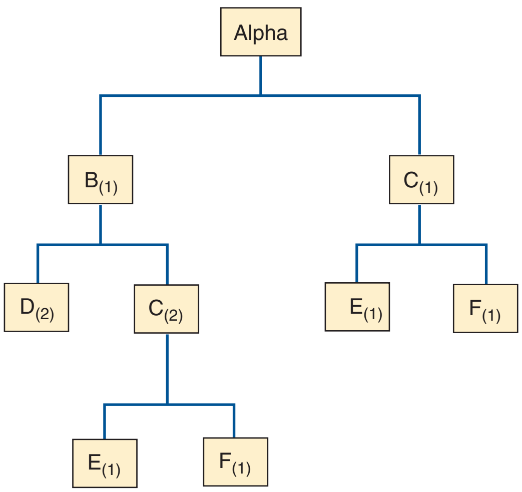
Virtual Office Hours help is available in MyOMLab.

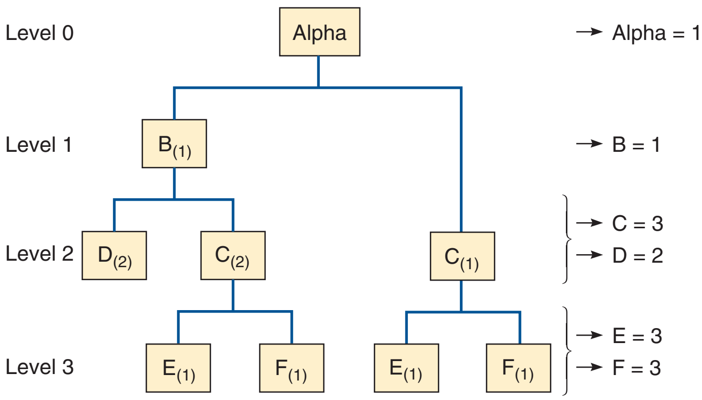
SOLVED PROBLEM 14.1

Determine the low-level coding and the quantity of each component necessary to produce 10 units of an assembly we will call Alpha. The product structure and quantities of each component needed for each assembly are noted in parentheses.

SOLUTION

Redraw the product structure with low-level coding. Then multiply down the structure until the requirements of each branch are determined. Then add across the structure until the total for each is determined.





Es required for left branch:

$$(1_{alpha} \times 1_B \times 2_C \times 1_E) = 2 \text{ Es}$$

and Es required for right branch:

$$(1_{alpha} \times 1_C \times 1_E) = \underline{1 \text{ E}}$$

3 Es required in total

Then "explode" the requirement by multiplying each by 10, as shown in the table to the right:

LEVEL	ITEM	QUANTITY PER UNIT	TOTAL REQUIREMENTS FOR 10 ALPHA
0	Alpha	1	10
1	B	1	10
2	C	3	30
2	D	2	20
3	E	3	30
3	F	3	30

SOLVED PROBLEM 14.2

Using the product structure for Alpha in Solved Problem 14.1, and the following lead times, quantity on hand, and master production schedule, prepare a net MRP table for Alphas.

ITEM	LEAD TIME	QUANTITY ON HAND
Alpha	1	10
B	2	20
C	3	0
D	1	100
E	1	10
F	1	50

Master Production Schedule for Alpha

PERIOD	6	7	8	9	10	11	12	13
Gross requirements			50			50		100

SOLUTION

See the chart on following page.

SOLVED PROBLEM 14.3

Hip Replacements, Inc., has a master production schedule for its newest model, as shown below, a setup cost of $50, a holding cost per week of $2, beginning inventory of 0, and lead time of 1 week. What are the costs of using lot-for-lot for this 10-week period?

SOLUTION

Holding cost = $0 (as there is never any end-of-period inventory)

Ordering costs = 4 orders × $50 = $200

Total cost for lot-for-lot = $0 + $200 = $200

WEEK		1	2	3	4	5	6	7	8	9	10
Gross requirements		0	0	50	0	0	35	15	0	100	0
Scheduled receipts											
Projected on hand	0	0	0	0	0	0	0	0	0	0	0
Net requirements		0	0	50	0	0	35	15	0	100	
Planned order receipts				50			35	15		100	
Planned order releases			50			35	15		100		

SOLVED PROBLEM 14.4

Hip Replacements, Inc., has a master production schedule for its newest model, as shown on page 592, a setup cost of $50, a holding cost per week of $2, beginning inventory of 0, and lead time of 1 week. What are the costs of using (a) EOQ and (b) POQ for this 10-week period?

SOLUTION

a) For the **EOQ** lot size, first determine the EOQ.

Annual usage = 200 units for 10 weeks; weekly usage = 200/10 weeks = 20 per week. Therefore, 20 units × 52 weeks (annual demand) = 1,040 units. From Chapter 12, the EOQ model is:

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

where D = annual demand = 1,040
S = Setup cost = $50
H = holding (carrying) cost, on an annual basis per unit = $2 × 52 = $104
Q^* = 31.62 ≈ 32 units (order the EOQ or in multiples of the EOQ)

(*Continued on page 592*)

Lot Size	Lead Time (# of Periods)	On Hand	Safety Stock	Allo-cated	Low-Level Code	Item ID			1	2	3	4	5	6	7	8	9	10	11	12	13
Lot-for-Lot	1	10	—	—	0	Alpha (A)	Gross Requirements									50			50		100
							Scheduled Receipts														
							Projected On Hand	10								10					
							Net Requirements									40			50		100
							Planned Order Receipts									40			50		
							Planned Order Releases								40			50		100	100
Lot-for-Lot	2	20	—	—	1	B	Gross Requirements								40(A)			50(A)		100(A)	
							Scheduled Receipts														
							Projected On Hand	20							20						
							Net Requirements								20			50		100	
							Planned Order Receipts								20			50		100	
							Planned Order Releases						20			50		100			
Lot-for-Lot	3	0	—	—	2	C	Gross Requirements						40(B)		40(A)	100(B)		200(B) + 50(A)		100(A)	
							Scheduled Receipts														
							Projected On Hand	0													
							Net Requirements						40		40	100		250		100	
							Planned Order Receipts						40		40	100		250		100	
							Planned Order Releases			40		40	100		250		100				
Lot-for-Lot	1	100	—	—	2	D	Gross Requirements						40(B)			100(B)		200(B)			
							Scheduled Receipts														
							Projected On Hand	100					100			60					
							Net Requirements						0			40		200			
							Planned Order Receipts						0			40		200			
							Planned Order Releases					0			40		200				
Lot-for-Lot	1	10	—	—	3	E	Gross Requirements			40(C)		40(C)	100(C)		250(C)		100(C)				
							Scheduled Receipts														
							Projected On Hand	10		10											
							Net Requirements			30		40	100		250		100				
							Planned Order Receipts			30		40	100		250		100				
							Planned Order Releases		30		40	100		250		100					
Lot-for-Lot	1	50	—	—	3	F	Gross Requirements			40(C)		40(C)	100(C)		250(C)		100(C)				
							Scheduled Receipts														
							Projected On Hand	50		50		10					—				
							Net Requirements			0		30	100		250		100				
							Planned Order Receipts					30	100		250		100				
							Planned Order Releases				30	100		250		100					

Net Material Requirements Planning Sheet for Alpha for Solved Problem 14.2

The letter in parentheses (A) is the source of the demand.

WEEK		1	2	3	4	5	6	7	8	9	10	
Gross requirements		0	0	50	0	0	35	15	0	100	0	
Scheduled receipts												
Projected on hand	0	0	0	0	14	14	14	11	28	28	24	24
Net requirements		0	0	50	0	0	21	0	0	72	0	
Planned order receipts				64			32	32		96		
Planned order releases			64			32	32		96			

Holding cost = 157 units × \$2 = \$314 (note the 24 units available in period 11, for which there is an inventory charge as they are in on-hand inventory at the end of period 10)

Ordering costs = 4 orders × \$50 = \$200

Total cost for EOQ lot sizing = \$314 + \$200 = \$514

b) For the **POQ** lot size we use the EOQ computed above to find the time period between orders:

Period interval = EOQ/average weekly usage = 32/20 = 1.6 ≈ 2 periods

POQ order size = Demand required in the 2 periods, postponing orders in periods with no demand.

WEEK		1	2	3	4	5	6	7	8	9	10
Gross requirements		0	0	50	0	0	35	15	0	100	0
Scheduled receipts											
Projected on hand	0	0	0	0	0	0	0	15	0	0	
Net requirements		0	0	50	0	0	50	0	0	100	0
Planned order receipts				50			50			100	
Planned order releases			50			50			100		

Holding cost = 15 units × \$2 = \$30

Ordering costs = 3 orders × \$50 = \$150

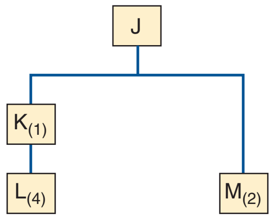
Total cost for POQ lot sizing = \$30 + \$150 = \$180

Problems*

Note: Px means the problem may be solved with POM for Windows and/or Excel OM. Many of the exercises in this chapter (14.1 through 14.16 and 14.29 through 14.32) can be done on *Resource Manager for Excel,* a commercial system made available by User Solutions, Inc. Access to a trial version of the software and a set of notes for the user are available at **www.usersolutions.com.**

Problems 14.1–14.4 relate to Dependent Inventory Model Requirements

• **14.1** You have developed the following simple product structure of items needed for your gift bag for a rush party for prospective pledges in your organization. You forecast 200 attendees. Assume that there is no inventory on hand of any of the items. Explode the bill of material. (Subscripts indicate the number of units required.)



•• **14.2** You are expected to have the gift bags in Problem 14.1 ready at 5 P.M. However, you need to personalize the items (monogrammed pens, note pads, literature from the printer, etc.). The lead time is 1 hour to assemble 200 Js once the other items are prepared. The other items will take a while as well. Given the volunteers you have, the other time estimates are item K (2 hours), item L (1 hour), and item M (4 hours). Develop a time-phased assembly plan to prepare the gift bags.

•• **14.3** As the production planner for Xiangling Hu Products, Inc., you have been given a bill of material for a bracket that is made up of a base, two springs, and four clamps. The base is assembled from one clamp and two housings. Each clamp has one handle and one casting. Each housing has two bearings and one shaft. There is no inventory on hand.

a) Design a product structure noting the quantities for each item and show the low-level coding.
b) Determine the gross quantities needed of each item if you are to assemble 50 brackets.
c) Compute the net quantities needed if there are 25 of the base and 100 of the clamp in stock. Px

•• **14.4** Your boss at Xiangling Hu Products, Inc., has just provided you with the schedule and lead times for the bracket in Problem 14.3. The unit is to be prepared in week 10. The lead times for the components are bracket (1 week), base (1 week), spring (1 week), clamp (1 week), housing (2 weeks), handle (1 week), casting (3 weeks), bearing (1 week), and shaft (1 week).

a) Prepare the time-phased product structure for the bracket.
b) In what week do you need to start the castings? Px

Problems 14.5–14.21 relate to MRP Structure

•• **14.5** The demand for subassembly S is 100 units in week 7. Each unit of S requires 1 unit of T and 2 units of U. Each unit of T requires 1 unit of V, 2 units of W, and 1 unit of X. Finally, each unit of U requires 2 units of Y and 3 units of Z. One firm manufactures all items. It takes 2 weeks to make S, 1 week to make T, 2 weeks to make U, 2 weeks to make V, 3 weeks to make W, 1 week to make X, 2 weeks to make Y, and 1 week to make Z.

a) Construct a product structure. Identify all levels, parents, and components.

b) Prepare a time-phased product structure.

•• **14.6** Using the information in Problem 14.5, construct a gross material requirements plan.

•• **14.7** Using the information in Problem 14.5, construct a net material requirements plan using the following on-hand inventory.

ITEM	ON-HAND INVENTORY	ITEM	ON-HAND INVENTORY
S	20	W	30
T	20	X	25
U	40	Y	240
V	30	Z	40

•• **14.8** Refer again to Problems 14.5 and 14.6. In addition to 100 units of S, there is also a demand for 20 units of U, which is a component of S. The 20 units of U are needed for maintenance purposes. These units are needed in week 6. Modify the *gross material requirements plan* to reflect this change.

•• **14.9** Refer again to Problems 14.5 and 14.7. In addition to 100 units of S, there is also a demand for 20 units of U, which is a component of S. The 20 units of U are needed for maintenance purposes. These units are needed in week 6. Modify the *net material requirements plan* to reflect this change.

•• **14.10**

a) Given the product structure and master production schedule (Figure 14.12 below), develop a gross requirements plan for all items.

b) Given the preceding product structure, master production schedule, and inventory status (Figure 14.12), develop a net materials requirements (planned order release) for all items.

••• **14.11** Given the product structure, master production schedule, and inventory status in Figure 14.13 on the next page and assuming the requirements for each BOM item is 1:

a) develop a gross requirements plan for Item C;

b) develop a net requirements plan for Item C.

•••• **14.12** Based on the data in Figure 14.13, complete a net material requirements schedule for:

a) All items (10 schedules in all), assuming the requirement for each BOM item is 1.

b) All 10 items, assuming the requirement for all items is 1, except B, C, and F, which require *2 each*.

••• **14.13** Electro Fans has just received an order for one thousand 20-inch fans due week 7. Each fan consists of a housing assembly, two grills, a fan assembly, and an electrical unit. The housing assembly consists of a frame, two supports, and a handle. The fan assembly consists of a hub and five blades. The electrical unit consists of a motor, a switch, and a knob. The following table gives lead times, on-hand inventory, and scheduled receipts.

a) Construct a product structure.

b) Construct a time-phased product structure.

c) Prepare a net material requirements plan.

Data Table for Problem 14.13

COMPONENT	LEAD TIME	ON-HAND INVENTORY	LOT SIZE*	SCHEDULED RECEIPT
20″ Fan	1	100	—	
Housing	1	100	—	
Frame	2	—	—	
Supports (2)	1	50	100	
Handle	1	400	500	
Grills (2)	2	200	500	
Fan Assembly	3	150	—	
Hub	1	—	—	
Blades (5)	2	—	100	
Electrical Unit	1	—	—	
Motor	1	—	—	
Switch	1	20	12	
Knob	1	—	25	200 knobs in week 2

* Lot-for-lot unless otherwise noted.

••• **14.14** A part structure, lead time (weeks), and on-hand quantities for product A are shown in Figure 14.14. From the information shown, generate:

a) An indented bill of material for product A (see Figure 5.9 in Chapter 5 as an example of a BOM).

b) Net requirements for each part to produce 10 As in week 8 using lot-for-lot.

••• **14.15** You are product planner for product A (in Problem 14.14 and Figure 14.14). The field service manager, Al Trostel, has just called and told you that the requirements for B and F should each be increased by 10 units for his repair requirements in the field.

a) Prepare a list showing the quantity of each part required to produce the requirements for the service manager *and* the production request of 10 Bs and Fs.

b) Prepare a net requirement plan by date for the new requirements (for both production and field service), assuming that the field service manager wants his 10 units of B and F in week 6 and the 10 production units of A in week 8.

Master Production Schedule for X1

PERIOD	7	8	9	10	11	12
Gross requirements		50		20		100

ITEM	LEAD TIME	ON HAND	ITEM	LEAD TIME	ON HAND
X1	1	50	C	1	0
B1	2	20	D	1	0
B2	2	20	E	3	10
A1	1	5			

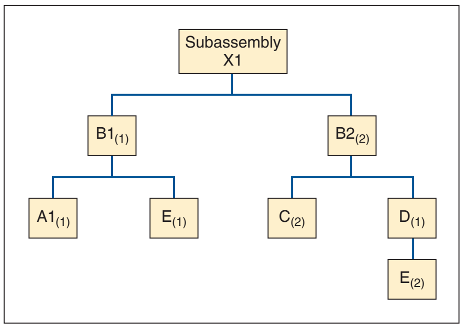


Figure **14.12**

Information for Problem 14.10

Period	8	9	10	11	12
Gross requirements: A	100		50		150
Gross requirements: H		100		50	

Item	On Hand	Lead Time	Item	On Hand	Lead Time
A	0	1	F	75	2
B	100	2	G	75	1
C	50	2	H	0	1
D	50	1	J	100	2
E	75	2	K	100	2

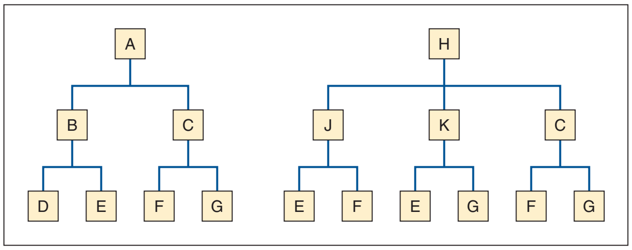


Figure 14.13

Information for Problems 14.11 and 14.12

• • • **14.16** You have just been notified via fax that the lead time for component G of product A (Problem 14.15 and Figure 14.14) has been increased to 4 weeks.

a) Which items have changed, and why?
b) What are the implications for the production plan?
c) As production planner, what can you do? PX

• • **14.17** Heather Adams, production manager for a Colorado exercise equipment manufacturer, needs to schedule an order for 50 UltimaSteppers, which are to be shipped in week 8. Subscripts indicate quantity required for each parent. Assume lot-for-lot ordering. Below is information about the steppers:

ITEM	LEAD TIME	ON-HAND INVENTORY	COMPONENTS
Stepper	2	20	$A_{(1)}$, $B_{(3)}$, $C_{(2)}$
A	1	10	$D_{(1)}$, $F_{(2)}$
B	2	30	$E_{(1)}$, $F_{(3)}$
C	3	10	$D_{(2)}$, $E_{(3)}$
D	1	15	
E	2	5	
F	2	20	

a) Develop a product structure for Heather.
b) Develop a time-phased structure.
c) Develop a net material requirements plan for F. PX

Additional problems **14.18–14.21** *are available in* MyOMLab.

Problems 14.22–14.28 relate to Lot-Sizing Techniques

Data Table for Problems 14.22 through 14.25*

PERIOD	1	2	3	4	5	6	7	8	9	10	11	12
Gross requirements	30		40		30	70	20		10	80		50

*Holding cost = \$2.50/unit/week; setup cost = \$150; lead time = 1 week; beginning inventory = 40; stockout cost = \$10.

• • • **14.22** Develop a lot-for-lot solution and calculate total relevant costs for the data in the preceding table. PX

• • • **14.23** Develop an EOQ solution and calculate total relevant costs for the data in the preceding table. PX

• • • **14.24** Develop a POQ solution and calculate total relevant costs for the data in the preceding table. PX

• • • **14.25** Using your answers for the lot sizes computed in Problems 14.22, 14.23, and 14.24, which is the best technique and why?

• • **14.26** M. de Koster, of Rene Enterprises, has the master production plan shown below:

Period (weeks)	1	2	3	4	5	6	7	8	9
Gross requirements		15		20		10			25

Lead time = 1 period; setup cost = \$200; holding cost = \$10 per week; stockout cost = \$10 per week. Your job is to develop an ordering plan and costs for:

a) Lot-for-lot. b) EOQ.
c) POQ. d) Which plan has the lowest cost? PX

14.27 Grace Greenberg, production planner for Science and Technology Labs, in New Jersey, has the master production plan shown below:

Period (weeks)	1	2	3	4	5	6	7	8	9	10	11	12
Gross requirements		35		40		10			25	10		45

Lead time = 1 period; setup costs = \$200; holding cost = \$10 per week; stockout cost = \$10 per week. Develop an ordering plan and costs for Grace, using these techniques:

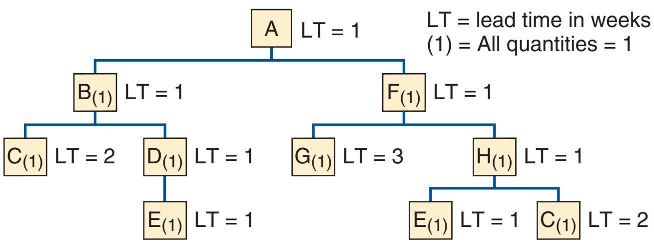
a) Lot-for-lot. b) EOQ.
c) POQ. d) Which plan has the lowest cost? PX

Figure 14.14

Information for Problems 14.14, 14.15, and 14.16

PART	INVENTORY ON HAND
A	0
B	2
C	10
D	5
E	4
F	5
G	1
H	10

PART STRUCTURE TREE



Additional problem **14.28** *is available in* MyOMLab.

Problems 14.29–14.32 relate to Extensions of MRP

• • • **14.29** Karl Knapps, Inc., has received the following orders:

Period	1	2	3	4	5	6	7	8	9	10
Order size	0	40	30	40	10	70	40	10	30	60

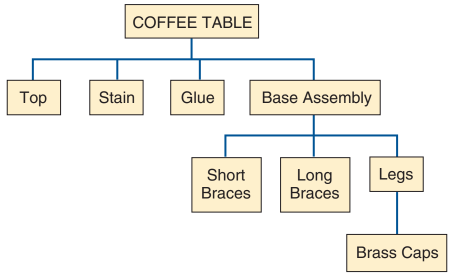
The entire fabrication for these units is scheduled on one machine. There are 2,250 usable minutes in a week, and each unit will take 65 minutes to complete. Develop a capacity plan, using lot splitting, for the 10-week time period.

• • • **14.30** Coleman Rich, Ltd., has received the following orders:

Period	1	2	3	4	5	6	7	8	9	10
Order size	60	30	10	40	70	10	40	30	40	0

The entire fabrication for these units is scheduled on one machine. There are 2,250 usable minutes in a week, and each unit will take 65 minutes to complete. Develop a capacity plan, using lot splitting, for the 10-week time period.

• • • **14.31** Courtney Kamauf schedules production of a popular Rustic Coffee Table at Kamauf Enterprises, Inc. The table requires a top, four legs, $\frac{1}{8}$ gallon of stain, $\frac{1}{16}$ gallon of glue, 2 short braces between the legs and 2 long braces between the legs, and a brass cap that goes on the bottom of each leg. She has 100 gallons of glue in inventory, but none of the other components. All items except the brass caps, stain, and glue are ordered on a lot-for-lot basis. The caps are purchased in quantities of 1,000, stain and glue by the gallon. Lead time is 1 day for each item. Schedule the order releases necessary to produce 640 coffee tables on days 5 and 6, and 128 on days 7 and 8. Px



• • • • **14.32** Using the data for the coffee table in Problem 14.31, build a labor schedule when the labor standard for each top is 2 labor-hours; each leg including brass cap installation requires $\frac{1}{4}$ hour, as does each pair of braces. Base assembly requires 1 labor-hour, and final assembly requires 2 labor-hours. What is the total number of labor-hours required each day, and how many employees are needed each day at 8 hours per day?

CASE STUDIES

When 18,500 Orlando Magic Fans Come to Dinner

Video Case

With vast experience at venues such as the American Airlines Arena (in Miami), the Kentucky Derby, and Super Bowls, Chef John Nicely now also plans huge culinary events at Orlando's Amway Center, home of the Orlando Magic basketball team. With his unique talent and exceptional operations skills, Nicely serves tens of thousands of cheering fans at some of the world's largest events. And when more than 18,500 basketball fans show up for a game, expecting great food and great basketball, he puts his creative as well as operations talent to work.

Chef John must be prepared. This means determining not only a total demand for all 18,500 fans, but also translating that demand into specific menu items and beverages. He prepares a forecast from current ticket sales, history of similar events at other venues, and his own records, which reflect the demand with this particular opponent, night of week, time of year, and even time of day. He then breaks the demand for specific menu items and quantities into items to be available at each of the 22 concession stands, 7 restaurants, and 68 suites. He must also be prepared to accommodate individual requests from players on both teams.

Chef John frequently changes the menu to keep it interesting for the fans who attend many of the 41 regular season home games each season. Even the culinary preference of the opponent's fans who may be attending influences the menu. Additionally, when entertainment other than the Magic is using the Amway Center, the demographic mix is likely to be different, requiring additional tweaking of the menu. The size of the wait staff and the kitchen staff change to reflect the size of the crowd; Chef John may be supervising as many as 90 people working in the kitchen. Similarly, the concessions stands, 40% of which have their own grills and fryers, present another challenge, as they are managed by volunteers from nonprofit organizations. The use of these volunteers adds the need for special training and extra enforcement of strict quality standards.

Once deciding on the overall demand and the menu, Chef John must prepare the production specifications (a bill of material) for each item. For the evening game with the Celtics, Chef John is preparing his unique *Cheeto Crusted Mac & Cheese* dish. The ingredients, quantity, costs, and labor requirements are shown below:

Production Specifications

CHEETO CRUSTED MAC & CHEESE (6 PORTIONS)					
INGREDIENTS	**QUANTITY**	**MEASURE**	**UNIT COST**	**TOTAL COST**	**LABOR-HOURS**
Elbow macaroni (large, uncooked)	20.00	oz.	$0.09	$1.80	
Cheese—cheddar shredded	10.00	oz.	0.16	1.60	
Mac and cheese base (see recipe)	44.00	oz.	0.80	35.20	
Milk	4.00	oz.	0.03	0.12	
Cheetos, crushed	6.00	oz.	0.27	1.62	
Sliced green onion—garnish	0.50	oz.	0.18	0.09	
Whole Cheetos—garnish	2.00	oz.	0.27	0.54	
Total labor hours					0.2 hours

The yield on this dish is 6 portions, and labor cost is $15 per hour, with fringes. The entire quantity required for the evening is prepared prior to the game and kept in warming ovens until needed. Demand for each basketball game is divided into 5 periods: prior to the game, first quarter, second quarter, half-time, and second half. At the Magic vs. Celtics game next week, the demand (number of portions) in each period is 60, 36, 48, 60, and 12 for the Cheeto Crusted Mac & Cheese dish, respectively.

Discussion Questions*

1. Prepare a bill of material explosion and total cost for the 216 portions of Cheeto Crusted Mac & Cheese.
2. What is the cost per portion? How much less expensive is the Cheeto Crusted Mac & Cheese than Chef John's alternative creation, the Buffalo Chicken Mac & Cheese, shown in Figure 14.9 of this chapter?
3. Assuming that there is no beginning inventory of the Cheeto Crusted Mac & Cheese and cooking time for the entire 216 portions is 0.6 hours, when must preparation begin?

*You may wish to view the video that accompanies this case before answering the questions.

MRP at Wheeled Coach

Video Case

Wheeled Coach, the world's largest manufacturer of ambulances, builds thousands of different and constantly changing configurations of its products. The custom nature of its business means lots of options and special designs—and a potential scheduling and inventory nightmare. Wheeled Coach addressed such problems, and succeeded in solving a lot of them, with an MRP system (described in the *Global Company Profile* that opens this chapter). As with most MRP installations, however, solving one set of problems uncovers a new set.

One of the new issues that had to be addressed by plant manager Lynn Whalen was newly discovered excess inventory. Managers discovered a substantial amount of inventory that was not called for in any finished products. Excess inventory was evident because of the new level of inventory accuracy required by the MRP system. The other reason was a new series of inventory reports generated by the IBM MAPICS MRP system purchased by Wheeled Coach. One of those reports indicates where items are used and is known as the "Where Used" report. Interestingly, many inventory items were not called out on bills of material (BOMs) for any current products. In some cases, the reason some parts were in the stockroom remained a mystery.

The discovery of this excess inventory led to renewed efforts to ensure that the BOMs were accurate. With substantial work, BOM accuracy increased and the number of engineering change notices (ECNs) decreased. Similarly, purchase-order accuracy, with regard to both part numbers and quantities ordered, was improved. Additionally, receiving department and stockroom accuracy went up, all helping to maintain schedule, costs, and ultimately, shipping dates and quality.

Eventually, Lynn Whalen concluded that the residual amounts of excess inventory were the result, at least in part, of rapid changes in ambulance design and technology. Another source was customer changes made after specifications had been determined and materials ordered. This latter excess occurs because, even though Wheeled Coach's own throughput time is only 17 days, many of the items that it purchases require much longer lead times.

Discussion Questions*

1. Why is accurate inventory such an important issue at Wheeled Coach?
2. Why does Wheeled Coach have excess inventory, and what kind of a plan would you suggest for dealing with it?
3. Be specific in your suggestions for reducing inventory and how to implement them.

*You may wish to view the video that accompanies this case before answering the questions.

- **Additional Case Studies:** Visit MyOMLab for these free case studies:
  Ikon's attempt at ERP: The giant office technology firm faces hurdles with ERP implementation.
  Hill's Automotive, Inc.: An after-market producer and distributor of auto replacement parts has trouble making MRP work.

Endnotes

1. The inventory models (EOQ) discussed in Chapter 12 assumed that the demand for one item was independent of the demand for another item. For example, EOQ assumes the demand for refrigerator parts is *independent* of the demand for refrigerators and that demand for parts is constant. MRP makes neither of these assumptions.
2. Record accuracy of 99% may sound good, but note that even when each component has an availability of 99% and a product has only seven components, the likelihood of a product being completed is only .932 (because $.99^7 = .932$).
3. Using EOQ is a convenient approach for determining the time between orders, but other rules can be used.
4. *Part period balancing, Silver-Meal,* and *Wagner-Whitin* are included in the software POM for Windows and ExcelOM, available with this text.

Chapter 14 *Rapid* Review

Main Heading	Review Material	MyOMLab
DEPENDENT DEMAND (p. 566)	Demand for items is *dependent* when the relationship between the items can be determined. For any product, all components of that product are dependent demand items. ■ **Material requirements planning (MRP)**—A dependent demand technique that uses a bill-of-material, inventory, expected receipts, and a master production schedule to determine material requirements.	Concept Questions: 1.1–1.4
DEPENDENT INVENTORY MODEL REQUIREMENTS (pp. 566–571)	Dependent inventory models require that the operations manager know the: (1) Master production schedule; (2) Specifications or bill of material; (3) Inventory availability; (4) Purchase orders outstanding; and (5) Lead times. ■ **Master production schedule (MPS)**—A timetable that specifies what is to be made and when. The MPS is a statement of *what is to be produced*, not a forecast of demand. ■ **Bill of material (BOM)**—A listing of the components, their description, and the quantity of each required to make one unit of a product. Items above any level in a BOM are called *parents*; items below any level are called *components*, or *children*. The top level in a BOM is the 0 level. ■ **Modular bills**—Bills of material organized by major subassemblies or by product options. ■ **Planning bills (or kits)**—Material groupings created in order to assign an artificial parent to a bill of material; also called "pseudo" bills. ■ **Phantom bills of material**—Bills of material for components, usually subassemblies, that exist only temporarily; they are never inventoried. ■ **Low-level coding**—A number that identifies items at the lowest level at which they occur. ■ **Lead time**—In purchasing systems, the time between recognition of the need for an order and receiving it; in production systems, it is the order, wait, move, queue, setup, and run times for each component. When a bill of material is turned on its side and modified by adding lead times for each component, it is called a *time-phased product structure*.	Concept Questions: 2.1–2.4 Problems: 14.1–14.4 Virtual Office Hours for Solved Problem: 14.1 **VIDEO 14.1** When 18,500 Orlando Magic Fans Come to Dinner **VIDEO 14.2** MRP at Wheeled Coach Ambulances
MRP STRUCTURE (pp. 571–575)	■ **Gross material requirements plan**—A schedule that shows the total demand for an item (prior to subtraction of on-hand inventory and scheduled receipts) and (1) when it must be ordered from suppliers, or (2) when production must be started to meet its demand by a particular date. ■ **Net material requirements**—The result of adjusting gross requirements for inventory on hand and scheduled receipts. ■ **Planned order receipt**—The quantity planned to be received at a future date. ■ **Planned order release**—The scheduled date for an order to be released. Net requirements = Gross requirements + Allocations − (On hand + Scheduled receipts)	Concept Questions: 3.1–3.4 Problems: 14.5–14.9, 14.11, 14.16–14.21 Virtual Office Hours for Solved Problem: 14.2 **ACTIVE MODEL 14.1**
MRP MANAGEMENT (pp. 575–576)	■ **System nervousness**—Frequent changes in an MRP system. ■ **Time fences**—A means for allowing a segment of the master schedule to be designated as "not to be rescheduled." ■ **Pegging**—In material requirements planning systems, tracing upward the bill of material from the component to the parent item. Four approaches for integrating MRP and JIT are (1) finite capacity scheduling, (2) small buckets, (3) balanced flow, and (4) supermarkets. ■ **Buckets**—Time units in a material requirements planning system. Finite capacity scheduling (FCS) considers department and machine capacity. FCS provides the precise scheduling needed for rapid material movement.	Concept Questions: 4.1–4.4
LOT-SIZING TECHNIQUES (pp. 576–580)	■ **Lot-sizing decision**—The process of, or techniques used in, determining lot size. ■ **Lot-for-lot**—A lot-sizing technique that generates exactly what is required to meet the plan. ■ **Periodic order quantity (POQ)**—A lot-sizing technique that issues orders on a predetermined time interval with an order quantity equal to all of the interval's requirements. In general, the lot-for-lot approach should be used whenever low-cost deliveries setup can be achieved.	Concept Questions: 5.1–5.4 Problems: 14.22, 14.26, 14.28

Chapter 14 *Rapid Review* *continued*

MyOMLab

Main Heading	Review Material	
EXTENSIONS OF MRP (pp. 580–583)	■ **Material requirements planning II (MRP II)**—A system that allows, with MRP in place, inventory data to be augmented by other resource variables; in this case, MRP becomes *material resource planning*. ■ **Closed-loop MRP system**—A system that provides feedback to the capacity plan, master production schedule, and production plan so planning can be kept valid at all times. ■ **Load report**—A report for showing the resource requirements in a work center for all work currently assigned there as well as all planned and expected orders. Tactics for smoothing the load and minimizing the impact of changed lead time include: *overlapping*, *operations splitting*, and *order splitting*, or *lot splitting*.	Concept Questions: 6.1–6.4 Problem: 14.32
MRP IN SERVICES (pp. 583–584)	■ **Distribution resource planning (DRP)**—A time-phased stock-replenishment plan for all levels of a distribution network.	Concept Questions: 7.1–7.4
ENTERPRISE RESOURCE PLANNING (ERP) (pp. 584–587)	■ **Enterprise resource planning (ERP)**—An information system for identifying and planning the enterprise-wide resources needed to take, make, ship, and account for customer orders. In an ERP system, data are entered only once into a common, complete, and consistent database shared by all applications. ■ **Efficient consumer response (ECR)**—Supply-chain management systems in the grocery industry that tie sales to buying, to inventory, to logistics, and to production.	Concept Questions: 8.1–8.4

Self Test

■ **Before taking the self-test,** refer to the learning objectives listed at the beginning of the chapter and the key terms listed at the end of the chapter.

LO 14.1 In a product structure diagram:
- **a)** parents are found only at the top level of the diagram.
- **b)** parents are found at every level in the diagram.
- **c)** children are found at every level of the diagram except the top level.
- **d)** all items in the diagrams are both parents and children.
- **e)** all of the above.

LO 14.2 The difference between a gross material requirements plan (gross MRP) and a net material requirements plan (net MRP) is:
- **a)** the gross MRP may not be computerized, but the net MRP must be computerized.
- **b)** the gross MRP includes consideration of the inventory on hand, whereas the net MRP doesn't include the inventory consideration.
- **c)** the net MRP includes consideration of the inventory on hand, whereas the gross MRP doesn't include the inventory consideration.
- **d)** the gross MRP doesn't take taxes into account, whereas the net MRP includes the tax considerations.
- **e)** the net MRP is only an estimate, whereas the gross MRP is used for actual production scheduling.

LO 14.3 Net requirements =
- **a)** Gross requirements + Allocations − On-hand inventory + Scheduled receipts.
- **b)** Gross requirements − Allocations − On-hand inventory − Scheduled receipts.
- **c)** Gross requirements − Allocations − On-hand inventory + Scheduled receipts.
- **d)** Gross requirements + Allocations − On-hand inventory − Scheduled receipts.

LO 14.4 A lot-sizing procedure that orders on a predetermined time interval with the order quantity equal to the total of the interval's requirement is:
- **a)** periodic order quantity.
- **b)** part period balancing.
- **c)** economic order quantity.
- **d)** all of the above.

LO 14.5 MRP II stands for:
- **a)** material resource planning.
- **b)** management requirements planning.
- **c)** management resource planning.
- **d)** material revenue planning.
- **e)** material risk planning.

LO 14.6 A(n) ______ MRP system provides information to the capacity plan, to the master production schedule, and ultimately to the production plan.
- **a)** dynamic
- **b)** closed-loop
- **c)** continuous
- **d)** retrospective
- **e)** introspective

LO 14.7 Which system extends MRP II to tie in customers and suppliers?
- **a)** MRP III
- **b)** JIT
- **c)** IRP
- **d)** ERP
- **e)** Enhanced MRP II

Answers: LO 14.1. c; LO 14.2. c; LO 14.3. d; LO 14.4. a; LO 14.5. a; LO 14.6. b; LO 14.7. d.