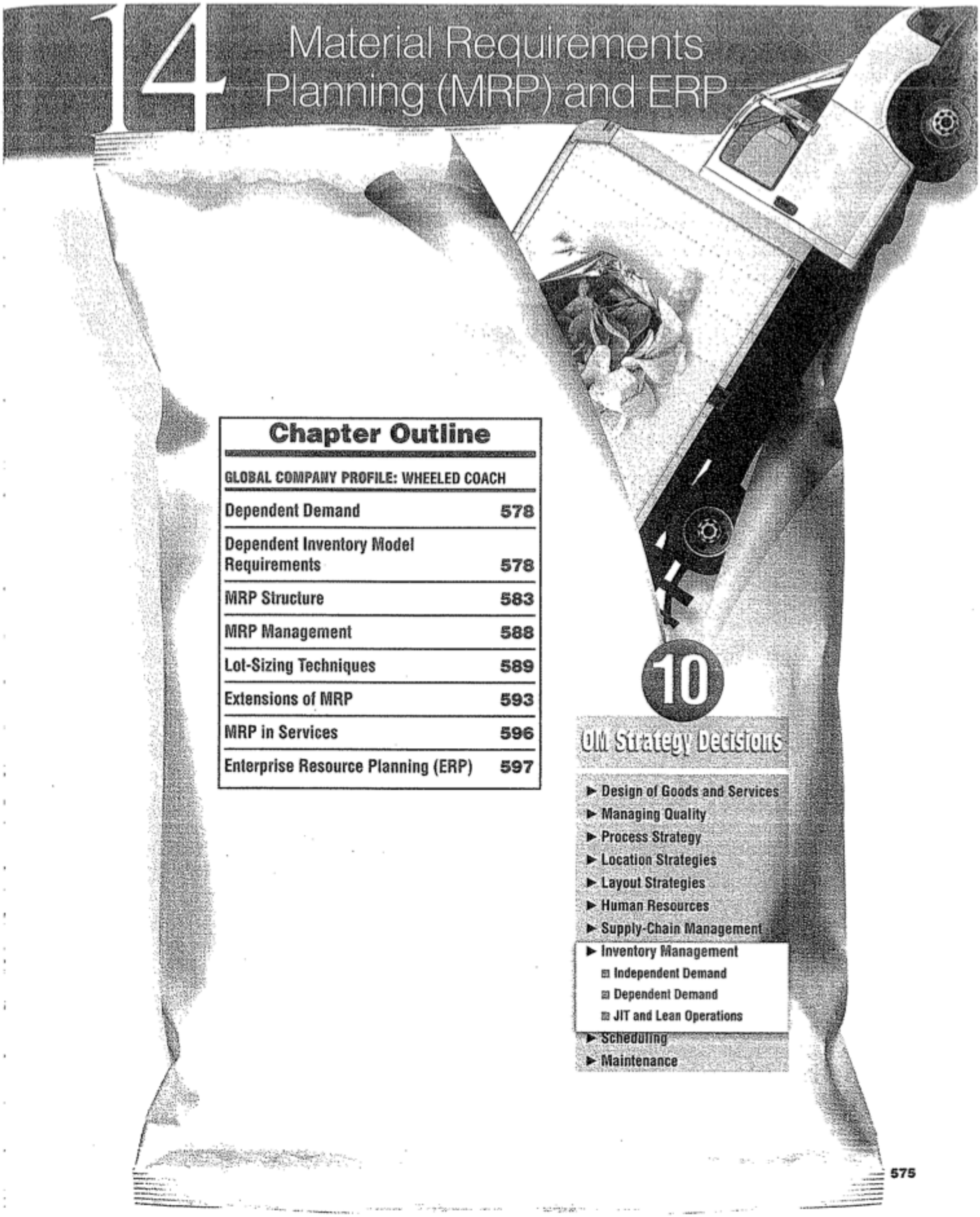
14 Material Requirements Planning (MRP) and ERP



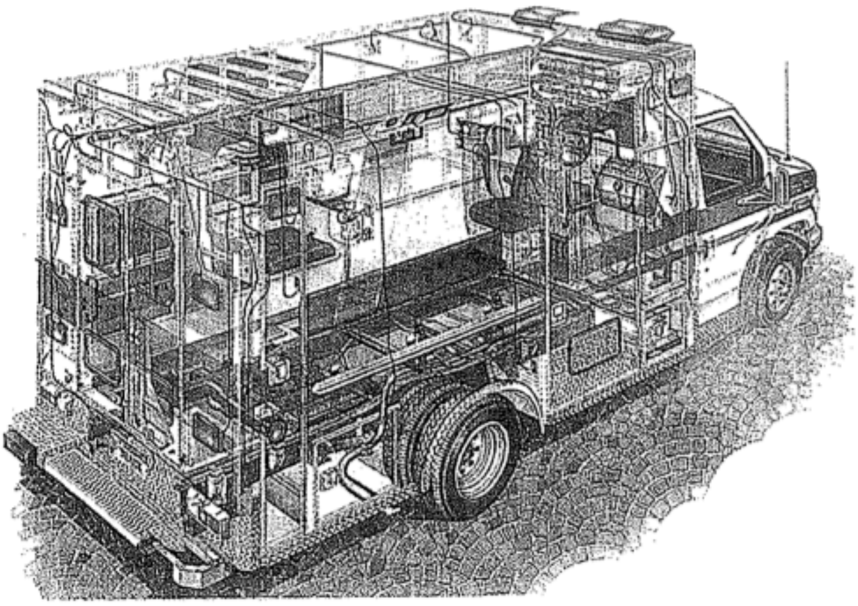
Chapter Outline

10 OM Strategy Decisions

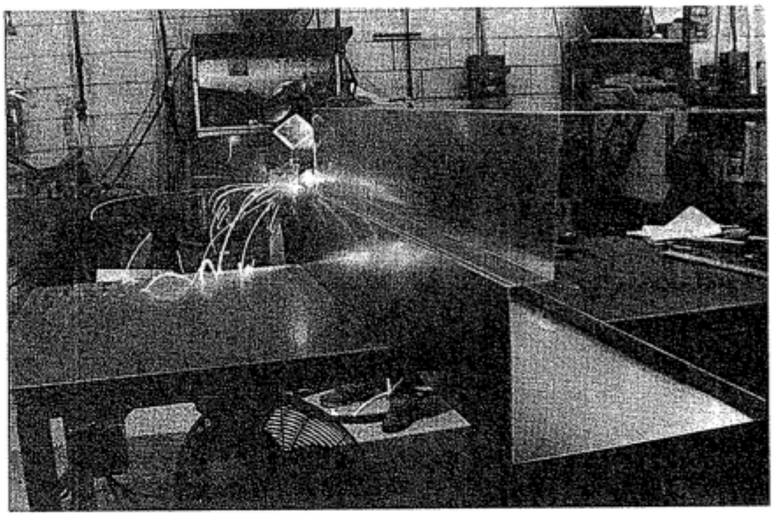
- Design of Goods and Services
- Managing Quality
- Process Strategy
- Location Strategies
- Layout Strategies
- Human Resources
- Supply-Chain Management
- Inventory Management
  - Independent Demand
  - Dependent Demand
  - JIT and Lean Operations
- Scheduling
- Maintenance

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 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



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 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).

demanded by the ambulance's application and customer preferences.

This variety of products and the nature of the process demand good material requirements planning. Effective use of an MRP system requires accurate bills of material and inventory records. The Wheeled Coach system, which uses MAPICS DB software, provides daily updates and has reduced inventory by more than 30% in just 2 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.

On six 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.

VIDEO 14.1
MRP at Wheeled Coach Ambulances

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.

Chapter 14 Learning Objectives

LO1: Develop a product structure	**581**	**LO5:** Describe MRP II	**594**
LO2: Build a gross requirements plan	**584**	**LO6:** Describe closed-loop MRP	**594**
LO3: Build a net requirements plan	**587**	**LO7:** Describe ERP	**597**
LO4: Determine lot sizes for lot-for-lot, EOQ, and PPB	**590**		

AUTHOR COMMENT "Dependent demand" means the demand for one item is related to the demand for another item.

DEPENDENT DEMAND

Wheeled Coach, the subject of the *Global Company Profile*, and many other firms have found important benefits in 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.*

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.

When the requirements of MRP are met, dependent models are preferable to the EOQ models 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)**.

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)

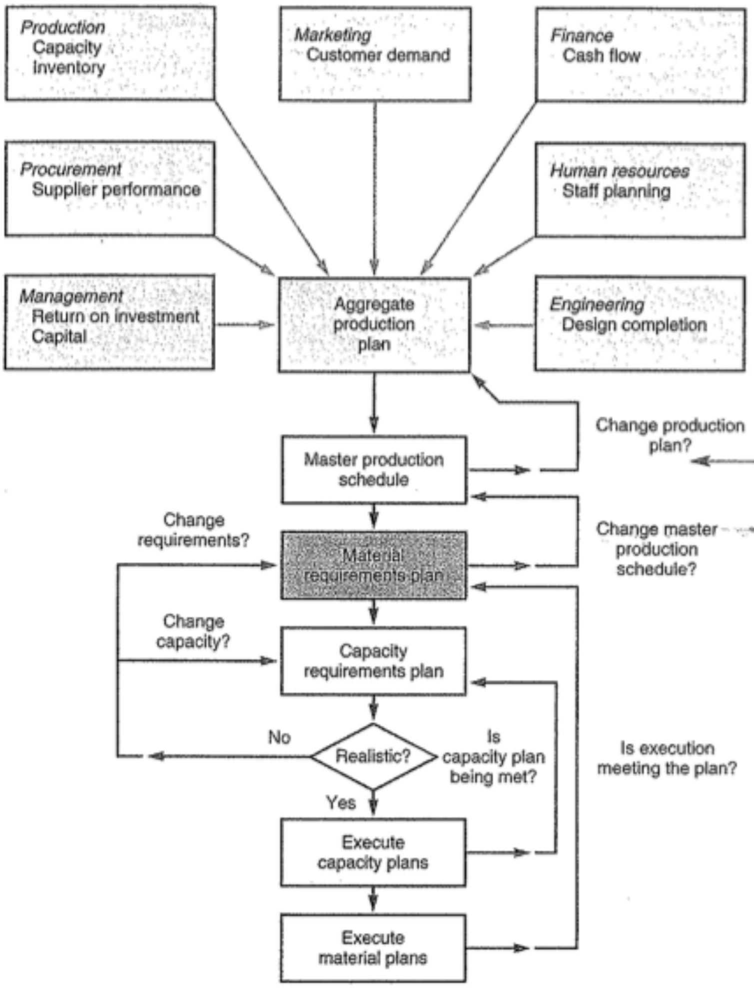
We now discuss each of these requirements in the context of material requirements planning.

Master Production Schedule

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

A **master production schedule (MPS)** specifies what is to be made (i.e., the number of finished products or items) and when. The schedule must be in accordance with a production plan. The production plan sets the overall level of output in broad terms (e.g., product families, standard

[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.



◄ **FIGURE 14.1**
The Planning Process

AUTHOR COMMENT
The master production schedule is derived from the aggregate schedule.

hours, or dollar volume). The plan also includes a variety of inputs, including financial plans, customer demand, engineering capabilities, labor availability, inventory fluctuations, supplier performance, and other considerations. Each of these inputs contributes in its own way to the production plan, as shown in Figure 14.1

As the planning process moves from the production plan to execution, each of the lower-level plans must be feasible. When one is not, feedback to the next higher level is used 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 production plan sets the upper and lower bounds on the master production schedule. The result of this production planning process is the master production schedule.

The master production schedule tells us what is required to satisfy demand and meet the production plan. This schedule establishes what items to make and when: It *disaggregates* the aggregate production plan. While the *aggregate production 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 production plan for a family of stereo amplifiers.

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"

▶ **FIGURE 14.2**
The Aggregate Production Plan Is the Basis for Development of the Detailed Master Production Schedule

Months	January				February			
Aggregate Production Plan (Shows the total quantity of amplifiers)	1,500				1,200			
Weeks	1	2	3	4	5	6	7	8
Master Production Schedule (Shows the specific type and quantity of amplifier to be produced)								
240-watt amplifier	100		100		100		100	
150-watt amplifier		500		500		450		450
75-watt amplifier			300				100	

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*, not a forecast of demand. The master schedule can be expressed in any of the following terms:

1. A *customer order in a job shop* (make-to-order) company
2. *Modules in a repetitive* (assemble-to-order or forecast) company
3. An *end item in a continuous* (stock-to-forecast) company

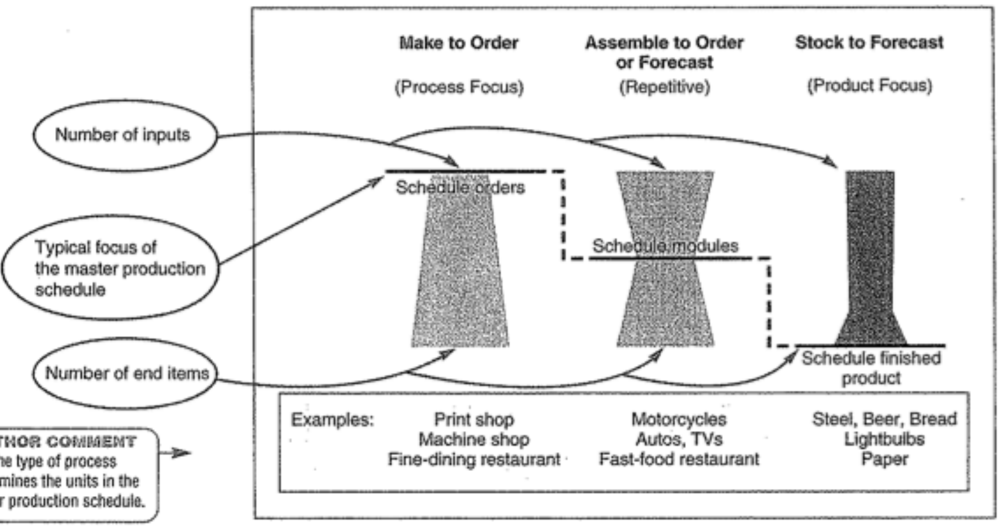
This relationship of the master production schedule to the processes is shown in Figure 14.3.

A master production schedule for two of Nancy's Specialty Foods' products, crabmeat quiche and spinach quiche, might look like 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. Nancy's Specialty



AUTHOR COMMENT The type of process determines the units in the master production schedule.

▲ **FIGURE 14.3** **Typical Focus of the Master Production Schedule in Three Process Strategies**

Gross Requirements for Crabmeat Quiche										
Day	6	7	8	9	10	11	12	13	14	and so on
Amount	50		100	47	60		110	75		

Gross Requirements for Spinach Quiche											
Day	7	8	9	10	11	12	13	14	15	16	and so on
Amount	100	200	150			60	75		100		

◄ **TABLE 14.1 Master Production Schedule for Crabmeat Quiche and Spinach Quiche at Nancy's Specialty Foods**

Foods has a recipe for quiche, specifying 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).

Because there is often a rush to get a new product to market, however, drawings and bills of material may be incomplete or even nonexistent. Moreover, complete drawings and BOMs (as well as other forms of specifications) often contain errors in dimensions, quantities, or countless other areas. When errors are identified, engineering change notices (ECNs) are created, further complicating the process. An *engineering change notice* is a change or correction to an engineering drawing or bill of material.

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

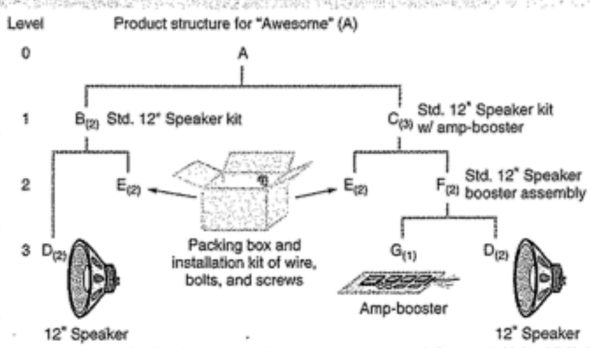
Speaker Kits, Inc., packages high-fidelity components for mail order. Components for the top-of-the-line speaker kit, "Awesome" (A), include 2 standard 12-inch speaker kits (Bs) and 3 speaker kits with amp-boosters (Cs).

Each B consists of 2 speakers (Ds) and 2 shipping boxes each with an installation kit (E). Each of the three 300-watt speaker kits (Cs) has 2 speaker boosters (Fs) and 2 installation kits (Es). Each speaker booster (F) includes 2 speakers (Ds) and 1 amp-booster (G). The total for each Awesome is 4 standard 12-inch speakers and twelve 12-inch speakers with the amp-booster. (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.

APPROACH ► Given the above information, we construct a product structure and "explode" the requirements.

LO1: Develop a product structure.

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.



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:	$2 \times$ number of As =	$(2)(50) =$	100
Part C:	$3 \times$ number of As =	$(3)(50) =$	150
Part D:	$2 \times$ number of Bs + $2 \times$ number of Fs =	$(2)(100) + (2)(300) =$	800
Part E:	$2 \times$ number of Bs + $2 \times$ number of Cs =	$(2)(100) + (2)(150) =$	500
Part F:	$2 \times$ number of Cs =	$(2)(150) =$	300
Part G:	$1 \times$ 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, 14.3a, 14.13a, 14.25a

EXCEL OM Data File **Ch14Ex1.xls** can be found at **www.pearsonglobaleditions.com/heizer**.

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 organized by major subassemblies or by product options.

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**. Bills of material are sometimes organized as modules (rather than as part of a final product) 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 configurations of the final product. This approach allows the MPS to be prepared for a reasonable number of items (the narrow portion of the middle graphic in Figure 14.3) and to postpone assembly. The 40 modules can then be configured for specific orders at final assembly.

Planning bills (or **kits**)
A material grouping 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. When the BOM has thousands of items or when requirements are frequently recomputed, the ease and speed of computation become a major concern.

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

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 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.

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.

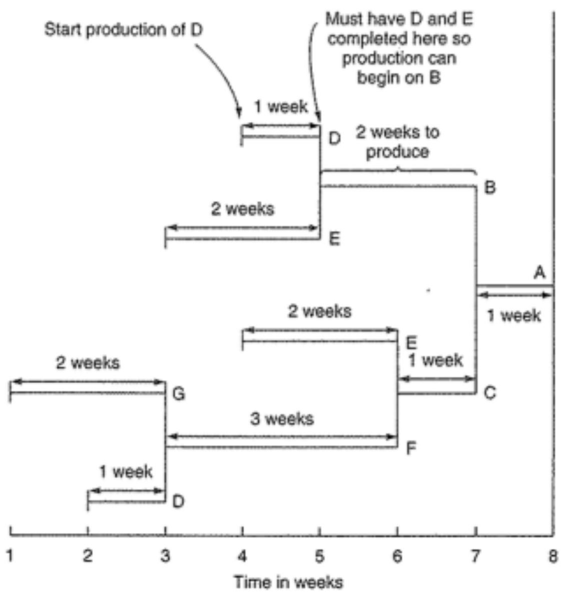
When the bill of material for Awesome speaker kits (As), in Example 1, is turned on its side and modified by adding lead times for each component (see Table 14.2), we then have a *time-phased product structure*. Time in this structure is shown on the horizontal axis of Figure 14.4 with item A due for 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

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 14.5).

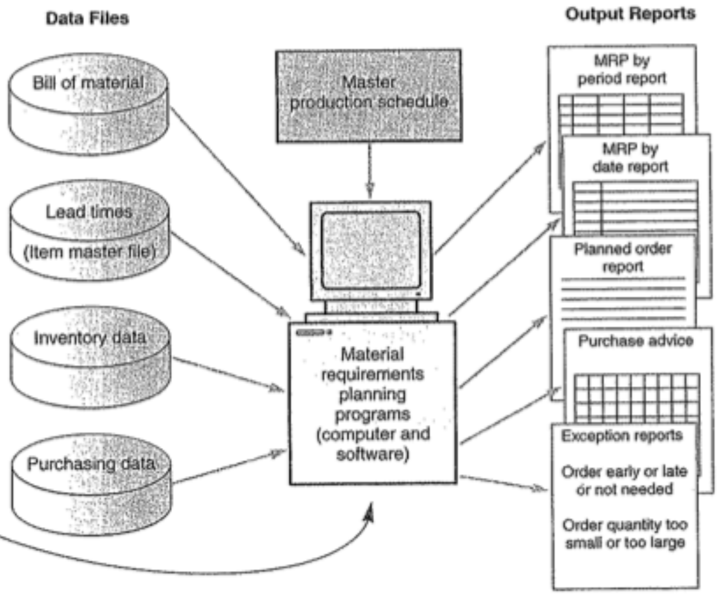


◄ FIGURE 14.4
Time-Phased Product Structure

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

[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 $.99^7 = .932$).

▶ FIGURE 14.5
Structure of the MRP System



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

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.

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 14.4). 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.

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)

	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

LO2: 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 ▶ 14.2, 14.4, 14.6, 14.8b, 14.9, 14.10a, 14.11a, 14.13b, 14.25b

So far, we have considered *gross material requirements*, which assumes that there is no inventory on hand. When there is inventory on hand, we prepare a **net requirements plan**. 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 Awesome speaker kits (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.

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

EXAMPLE 3
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.

Item	On Hand	Item	On Hand
A	10	E	10
B	15	F	5
C	20	G	0
D	10		

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 chart on the next 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 1-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.

▼ **Net Material Requirements Plan for Product A** *(the superscript is the source of the demand)*

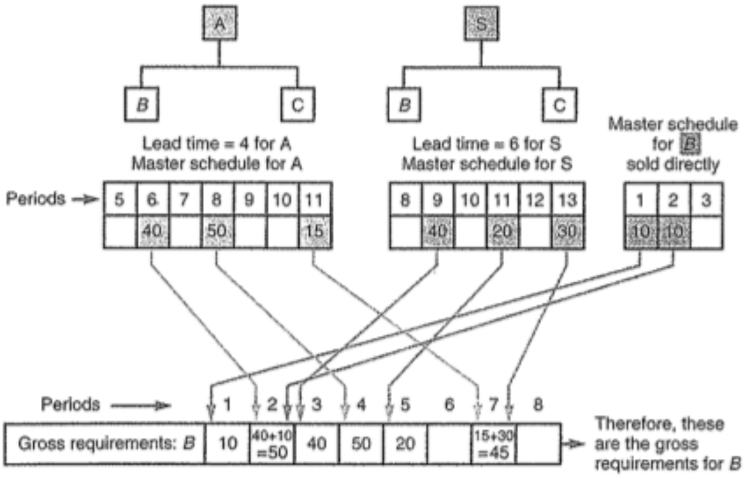
Lot Size	Lead Time (weeks)	On Hand	Safety Stock	Allo-cated	Low-Level Code	Item Identi-fication			Week 1	2	3	4	5	6	7	8
Lot-for-Lot	1	10	—	—	0	A	Gross Requirements									50
							Scheduled Receipts									
							Projected On Hand	10	10	10	10	10	10	10	10	10
							Net Requirements									40
							Planned Order Receipts									40
							Planned Order Releases								40	
Lot-for-Lot	2	15	—	—	1	B	Gross Requirements								80^A	
							Scheduled Receipts									
							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									
							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									
							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									
							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									
							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									
							Projected On Hand				0					
							Net Requirements				195					
							Planned Order Receipts				195					
							Planned Order Releases		195							

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 ▶ 14.5, 14.7, 14.8c, 14.10b, 14.11b, 14.12, 14.13c, 14.14b, 14.15a,b,c, 14.16a, 14.25c, 14.27

ACTIVE MODEL 14.1 This example is further illustrated in Active Model 14.1 at **www.pearsonglobaleditions.com/heizer.**

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



◄ **FIGURE 14.6 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.

AUTHOR COMMENT MRP gross requirements can combine multiple products, spare parts, and items sold directly.

master schedule and ultimately to the net material requirements plan. Figure 14.6 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 referred to as *allocated* items. Allocated items increase requirements and may then be included in an MRP planning sheet, as shown in Figure 14.7.

The allocated quantity has the effect of increasing the requirements (or, alternatively, reducing the quantity on hand). The logic, then, of a net requirements MRP is:

$$\underbrace{[(\text{Gross requirements}) + (\text{Allocations})]}_{\text{Total requirements}} - \underbrace{[(\text{On hand}) + (\text{Scheduled receipts})]}_{\text{Available inventory}} = \text{Net requirements}$$

LO3: Build a net requirements plan

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 the projected on-hand inventory of the MRP logic. Distortion can be minimized when safety stock is held at the finished goods level and at the purchased component or raw material level.

▼ **FIGURE 14.7 Sample MRP Planning Sheet for Item Z**

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	

AUTHOR COMMENT
Using MRP to the utmost is serious work.

MRP MANAGEMENT

The material requirements plan is not static. And since MRP systems increasingly are integrated with just-in-time (JIT) techniques, we now discuss these two issues.

MRP Dynamics

Bills of material and material requirements plans are altered as changes in design, schedules, and production processes occur. In addition, changes occur in material requirements whenever the master production schedule is modified. Regardless of the cause of any changes, the MRP model can be manipulated to reflect them. In this manner, an up-to-date requirements schedule is possible.

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. This occurs in one of two ways: by recomputing (also known as "regenerating") the requirement and schedule periodically, often weekly, or via a "net change" calculation. Net change in an MRP system means the MRP system creates new requirements in response to transactions. 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.

System nervousness
Frequent changes in an MRP system.

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.

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 in the bill of material from the component to the parent item.

With MRP, the operations manager *can* react to the dynamics of the real world. How frequently the manager wishes to impose those changes on the firm requires professional judgment. Moreover, if the nervousness is caused by legitimate changes, then the proper response may be to investigate the production environment—not adjust via MRP.

MRP and JIT

MRP does not do detailed scheduling—it plans. MRP will tell you that a job needs to be completed on a certain week or day but does not tell you 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. Fixed lead times can be a limitation. For instance, the lead time to produce 50 units may vary substantially from the lead time to produce 5 units. These limitations complicate the marriage of MRP and just-in-time (JIT). What is needed is a way to make MRP more responsive to moving material rapidly in small batches. An MRP system combined with JIT can provide the best of both worlds. MRP provides the plan and an accurate picture of requirements; then JIT rapidly moves material in small batches, reducing work-in-process inventory. Let's look at four approaches for integrating MRP and JIT: finite capacity scheduling, small buckets, balanced flow, and supermarkets.

Finite Capacity Scheduling (FCS) Most MRP software loads work into infinite size "buckets." The **buckets** are time units, usually one week. Traditionally, when work is to be done in a given week, MRP puts the work there without regard to capacity. Consequently, MRP is considered an *infinite* scheduling technique. Frequently, as you might suspect, this is not realistic. Finite capacity scheduling (FCS), which we discuss in Chapter 15, considers department and machine capacity, which is *finite*, hence the name. FCS provides the precise scheduling needed for rapid material movement. We are now witnessing a convergence of FCS and MRP. Sophisticated FCS systems modify the output from MRP systems to provide a finite schedule.

Buckets
Time units in a material requirements planning system.

Small Bucket Approach MRP is an excellent tool for resource and scheduling management in process-focused facilities, that is, in job shops. Such facilities include machine shops, hospitals, and restaurants, where lead times are relatively stable and poor balance between work centers is expected. Schedules are often driven by work orders, and lot sizes are the exploded bill-of-material size. In these enterprises, MRP can be integrated with JIT through the following steps.

STEP 1: Reduce MRP "buckets" from weekly to daily to perhaps hourly. Buckets are time units in an MRP system. Although the examples in this chapter have used weekly *time buckets*, many firms now use daily or even fraction-of-a-day time buckets. Some systems use a **bucketless system** in which all time-phased data have dates attached rather than defined time periods or buckets.

STEP 2: The planned receipts that are part of a firm's planned orders in an MRP system are communicated to the work areas for production purposes and used to sequence production.

STEP 3: Inventory is moved through the plant on a JIT basis.

STEP 4: As products are completed, they are moved into inventory (typically finished-goods inventory) in the normal way. Receipt of these products into inventory reduces the quantities required for subsequent planned orders in the MRP system.

STEP 5: A system known as *back flush* is used to reduce inventory balances. **Back flushing** uses the bill of material to deduct component quantities from inventory as each unit is completed.

Bucketless system
Time-phased data are referenced using dated records rather than defined time periods, or buckets.

Back flush
A system to reduce inventory balances by deducting everything in the bill of material on completion of the unit.

The focus in these facilities becomes one of maintaining schedules. Nissan achieves success with this approach by computer communication links to suppliers. These schedules are confirmed, updated, or changed every 15 to 20 minutes. Suppliers provide deliveries 4 to 16 times per day. Master schedule performance is 99% on time, as measured every hour. On-time delivery from suppliers is 99.9% and for manufactured piece parts, 99.5%.

Balanced Flow Approach MRP supports the planning and scheduling necessary for repetitive operations, such as the assembly lines at Harley-Davidson, Whirlpool, and a thousand other places. In these environments, the planning portion of MRP is combined with JIT execution. The JIT portion uses kanbans, visual signals, and reliable suppliers to pull the material through the facility. In these systems, execution is achieved by maintaining a carefully balanced flow of material to assembly areas with small lot sizes.

Supermarket Another technique that joins MRP and JIT is the use of a "supermarket." In many firms, subassemblies, their components, and hardware items are common to a variety of products. In such cases, releasing orders for these common items with traditional lead-time offset, as is done in an MRP system, is not necessary. The subassemblies, components, and hardware items can be maintained in a common area, sometimes called a **supermarket**, adjacent to the production areas where they are used. For instance, Ducati, Italy's high-performance motorcycle manufacturer, pulls "kits" with the materials needed for one engine or vehicle from the supermarket and delivers them to the assembly line on a JIT basis. Items in the supermarket are replenished by a JIT/kanban system.

Supermarket
An inventory area that holds common items that are replenished by a kanban system.

LOT-SIZING TECHNIQUES

AUTHOR COMMENT
Managers need to know how to group/order the "planned order releases."

An MRP system is an excellent way to determine production schedules and net requirements. However, whenever we have a net requirement, a decision must be made about *how much* 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-sizing decision
The process of, or techniques used in, determining lot size.

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 and just-in-time inventory techniques implemented, lot-for-lot can be very efficient. However, when setup costs are significant or management has been unable to implement JIT, lot-for-lot can be expensive. Example 4 uses the lot-for-lot criteria and determines cost for 10 weeks of demand.

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

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 the 12-inch speaker unit, 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*

		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 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 × 1 = 0; ordering cost = 7 × 100 = 700.)

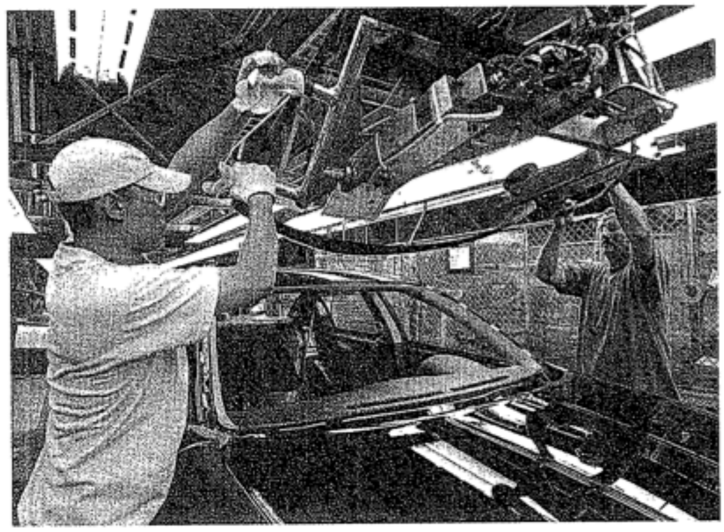
INSIGHT ▶ When supply is reliable and frequent orders are inexpensive, but holding cost or obsolescence is high, lot-for-lot ordering can be very efficient.

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 ▶ 14.17, 14.20, 14.21, 14.22

LO4: Determine lot sizes for lot-for-lot, EOQ, and PPB

Economic Order Quantity As discussed in Chapter 12, EOQ can be used as a lot-sizing technique. But as we indicated there, EOQ is preferable when *relatively constant* independent demand exists, not when we *know* the demand. EOQ is a statistical technique using averages (such as average demand for a year), whereas the MRP procedure assumes *known* (dependent)



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.

demand reflected in a master production schedule. Operations managers should take advantage of demand information when it is known, rather than assuming a constant demand. EOQ is examined in Example 5.

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 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

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

MRP Lot Sizing: EOQ Technique*

		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.

$$\text{Setups} = 1{,}404/73 = 19 \text{ per year}$$
$$\text{Annual Setup cost} = 19 \times \$100 = \$1{,}900$$
$$\text{Annual Holding cost} = \tfrac{73}{2} \times (\$1 \times 52 \text{ weeks}) = \$1{,}898$$
$$\text{Annual Setup cost} + \text{Holding cost} = \$1{,}900 + 1{,}898 = \$3{,}798$$

The EOQ solution yields a computed 10-week cost of $730 [$3,798 × (10 weeks/52 weeks) = $730].

INSIGHT ▶ EOQ can be an effective lot-sizing technique when demand is relatively constant. However, notice that actual holding cost will vary from the computed $730, depending on the rate of actual usage. From the preceding table, we can see that in our 10-week example, costs really are $400 for four setups, plus a holding cost of 375 units (includes 57 remaining at the end of the period) at $1 per week for a total of $775. Because usage was not constant, the actual computed cost was in fact more than the theoretical EOQ ($730) and the lot-for-lot rule ($700). 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 ▶ 14.18, 14.20, 14.21, 14.22

Part Period Balancing **Part period balancing (PPB)** is a more dynamic approach to balance setup and holding cost.[3] PPB uses additional information by changing the lot size to reflect requirements of the next lot size in the future. PPB attempts to balance setup and holding cost for

Part period balancing (PPB)
An inventory ordering technique that balances setup and holding costs by changing the lot size to reflect requirements of the next lot size in the future.

[3] J. J. DeMatteis, "An Economic Lot-Sizing Technique: The Part-Period Algorithms," *IBM Systems Journal* 7 (1968): 30–38.

Economic part period (EPP)
A period of time when the ratio of setup cost to holding cost is equal.

known demands. Part period balancing develops an **economic part period (EPP)**, which is the ratio of setup cost to holding cost. For our Speaker Kits example, EPP = \$100/\$1 = 100 units. Therefore, holding 100 units for one period would cost \$100, exactly the cost of one setup. Similarly, holding 50 units for two periods also costs \$100 (2 periods × \$1 × 50 units). PPB merely adds requirements until the number of part periods approximates the EPP—in this case, 100. Example 6 shows the application of part period balancing.

EXAMPLE 6 ▶

Lot sizing with part period balancing

Speaker Kits, Inc., wants to compute the costs associated with lot sizing using part period balancing. It will use a setup cost of \$100 and a \$1 holding cost.

APPROACH ▶ Using the same costs and production schedule as Examples 3 and 4, we develop a format that helps us compute the PPB quantity and apply that to our net requirements plan.

SOLUTION ▶ The procedure for computing the order releases of 80, 100, and 55 is shown in the following PPB calculation. In the second table, we apply the PPB order quantities to the net requirements plan.

PPB Calculations

Periods Combined	Trial Lot Size (cumulative net requirements)	Part Periods	Costs: Setup	Costs: Holding	Costs: Total
2	30	0	**40 units held for 1 period = \$40**		
2, 3	70	40 = 40 × 1	**10 units held for 3 periods = \$30**		
2, 3, 4	70	40			
2, 3, 4, 5	80	70 = 40 × 1 + 10 × 3	100 +	70 =	170
2, 3, 4, 5, 6	120	230 = 40 × 1 + 10 × 3 + 40 × 4			
(Therefore, combine periods 2 through 5; 70 is as close to our EPP of 100 as we are going to get.)					
6	40	0			
6, 7	70	30 = 30 × 1			
6, 7, 8	70	30 = 30 × 1 + 0 × 2			
6, 7, 8, 9	100	120 = 30 × 1 + 30 × 3	100 +	120 =	220
(Therefore, combine periods 6 through 9; 120 is as close to our EPP of 100 as we are going to get.)					
10	55	0	100 +	0 =	100
			300 +	190 =	490

MRP Lot Sizing: PPB Technique*

		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	50	10	10	0	60	30	30	0
Net requirements		0	30	0	0	0	40	0	0	0	55
Planned order receipts			80				100				55
Planned order releases		80				100				55	

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

EPP is 100 (setup cost divided by holding cost = \$100/\$1). The first lot is to cover periods 2, 3, 4, and 5 and is 80.

The total costs are \$490, with setup costs totaling \$300 and holding costs totaling \$190.

INSIGHT ▶ Both the EOQ and PPB approaches to lot sizing balance holding cost and ordering cost. But PPB places an order each time holding cost equals ordering cost, while EOQ takes a longer averaging approach.

LEARNING EXERCISE ▶ What is the impact on total cost if holding cost is \$2 per period rather than \$1? [Answer: With higher holding costs [PPB becomes 100/2 = 50], reorder points become more frequent, with orders now being placed for 70 units in period 1, 50 in period 4, 60 in period 6, and 55 in period 9.]

RELATED PROBLEMS ▶ 14.19, 14.20, 14.21, 14.22

Wagner-Whitin Algorithm The **Wagner-Whitin procedure** is a dynamic programming model that adds some complexity to the lot-size computation. It assumes a finite time horizon beyond which there are no additional net requirements. It does, however, provide good results.[4]

Wagner-Whitin procedure
A technique for lot-size computation that assumes a finite time horizon beyond which there are no additional net requirements to arrive at an ordering strategy.

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

Lot-for-lot	$700
EOQ	$730
Part period balancing	$490

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. However, 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 respond to frequent changes.

In general, the lot-for-lot approach should be used whenever low-cost deliveries 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, part period balancing (PPB), Wagner-Whitin, 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.

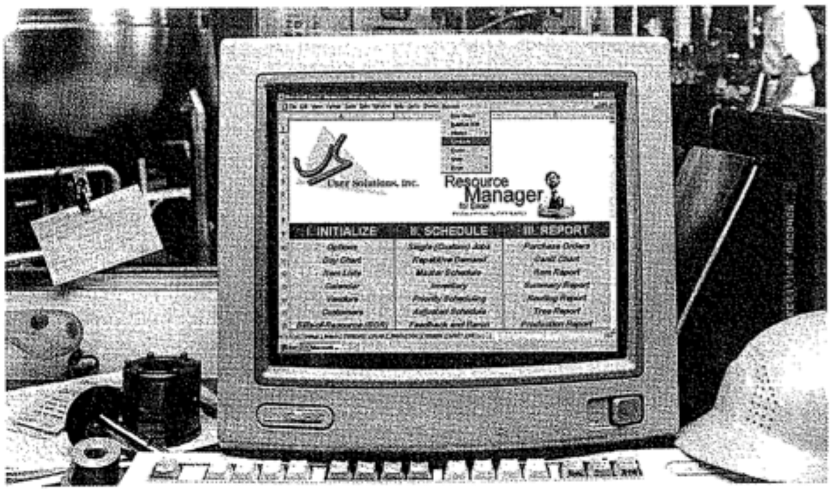
EXTENSIONS OF MRP

In this section, we review three extensions of MRP.

Material Requirements Planning II (MRP II)

Material requirements planning II 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.

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.*



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

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

[4]We leave discussion of the algorithm to mathematical programming texts. The Wagner-Whitin algorithm yields a cost of $455 for the data in Examples 4, 5, and 6.

▶ TABLE 14.4
Material Resource Planning (MRP II)

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

	Lead Time	WEEKS 5	6	7	8
Computer	1				100
Labor-hours: .2 each					20
Machine-hours: .2 each					20
Scrap: 1 ounce fiberglass each					6.25 lbs
Payables: $0					$0
PC board (1 each)	2			100	
Labor-hours: .15 each				15	
Machine-hours: .1 each				10	
Scrap: .5 ounces copper each				3.125 lb	
Payables: raw material at $5 each				$500	
Processors (5 each)	4	500			
Labor-hours: .2 each		100			
Machine-hours: .2 each		100			
Scrap: .01 ounces of acid waste each		0.3125 lb			
Payables: processors at $10 each		$5,000			

LO5: Describe MRP II

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 the environmental and sustainability issues, identifying and managing byproducts becomes increasingly important. MRP II provides a vehicle for doing so. Table 14.4 provides an example of labor-hours, machine-hours, 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.

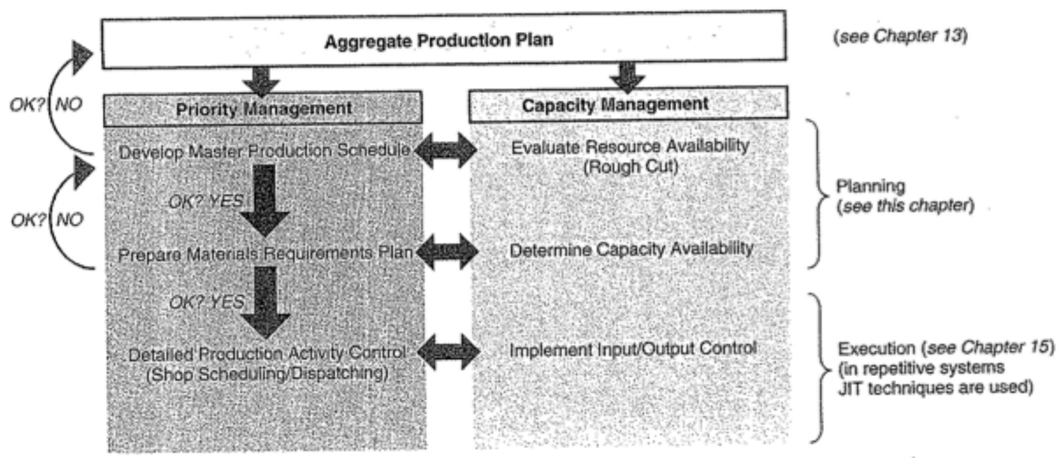
MRP II systems are seldom stand-alone programs. Most are tied into other computer software that provide data to the MRP system or receive data from the MRP system. Purchasing, production scheduling, capacity planning, inventory, and warehouse management are a few examples of this data integration.

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.

LO6: Describe closed-loop MRP

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 14.8). Virtually all commercial MRP systems are closed-loop.

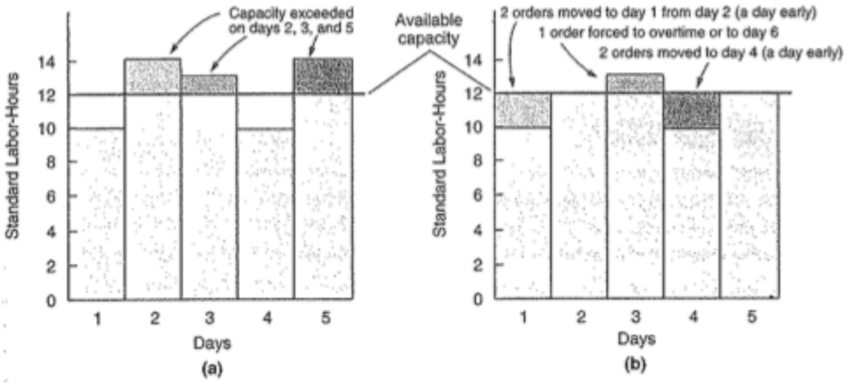


▲ FIGURE 14.8 Closed-Loop Material Requirements Planning

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. Figure 14.9(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 14.8.) The closed-loop MRP system can then reschedule all items in the net requirements plan (see Figure 14.9[b]).

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.



◄ FIGURE 14.9
(a) Initial Resource Requirements Profile for a Work Center (b) Smoothed Resource Requirements Profile for a Work Center

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* 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 ▶ 14.23, 14.24

When the workload consistently exceeds work-center capacity, the tactics just discussed are not adequate. This may mean adding capacity. Options include 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. MRP 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 14.10 shows (a) a product-structure tree and (b) a bill of material for veal picante, a top-selling entrée in a New Orleans restaurant. Note that the various components of veal picante (that is, veal, sauce, spinach, and linguini) are prepared by different kitchen personnel (see part [a] of Figure 14.10). These preparations also require different amounts of time to complete. Figure 14.10(c) shows a bill-of-labor for the veal dish. It lists the operations to be performed, the order of operations, and the labor requirements for each operation (types of labor and labor-hours).

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 (BOM) 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)

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

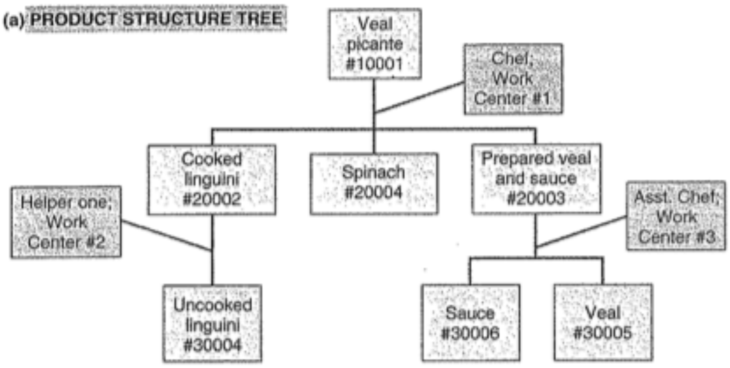
When dependent techniques are used in the supply chain, they are called distribution resource planning (DRP). **Distribution resource planning (DRP)** is a time-phased stock-replenishment plan for all levels of the supply chain.

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.[5]

[5]For an expanded discussion of time-phased stock-replenishment plans, see the section "Opportunities in an Integrated Supply Chain" in Chapter 11 of this text.

(a) PRODUCT STRUCTURE TREE



(b) BILL OF MATERIALS

Part Number	Description	Quantity	Unit of Measure	Unit Cost
10001	Veal picante	1	Serving	—
20002	Cooked linguini	1	Serving	—
20003	Prepared veal and sauce	1	Serving	—
20004	Spinach	0.1	Bag	0.94
30004	Uncooked linguini	0.5	Pound	—
30005	Veal	1	Serving	2.15
30006	Sauce	1	Serving	0.80

(c) BILL OF LABOR FOR VEAL PICANTE

			Labor-Hours	
Work Center	Operation	Labor Type	Setup Time	Run Time
1	Assemble dish	Chef	.0069	.0041
2	Cook linguini	Helper one	.0005	.0022
3	Cook veal and sauce	Assistant chef	.0125	.0500

◄ **FIGURE 14.10**
Product Structure Tree, Bill-of-Material, and Bill-of-Labor for Veal Picante

Source: Adapted from John G. Wacker, "Effective Planning and Cost Control for Restaurants," *Production and Inventory Management* (Vol. 26, no. 1): 60. Reprinted by permission of American Production and Inventory Control Society.

ENTERPRISE RESOURCE PLANNING (ERP)

AUTHOR COMMENT
ERP tries to integrate all of a firm's information.

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 14.11.

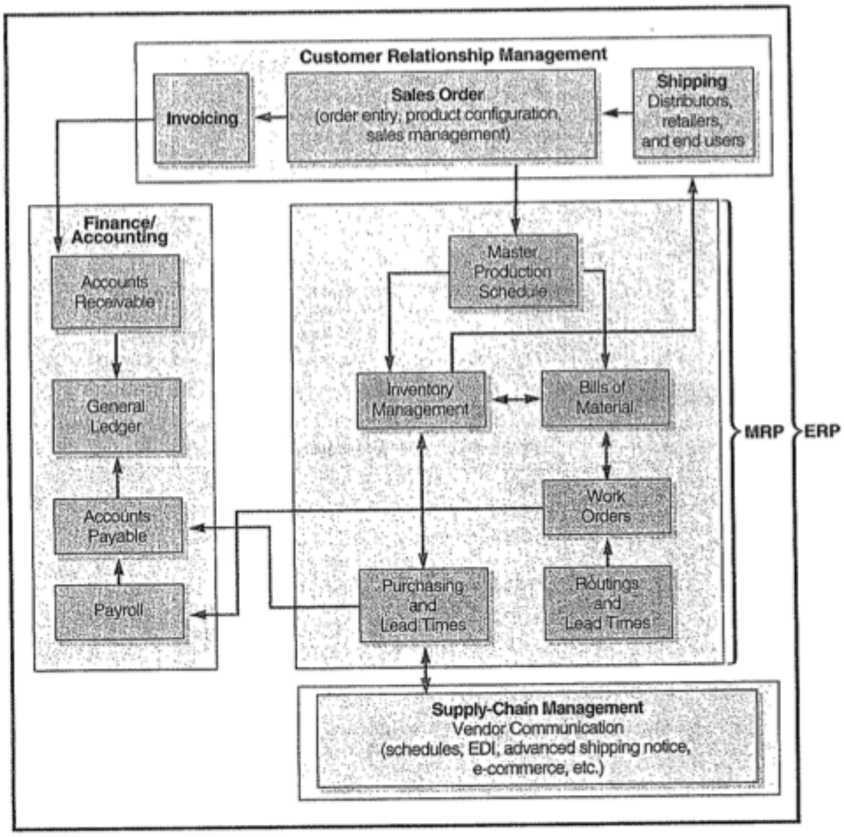
Enterprise resource planning (ERP)
An information system for identifying and planning the enterprise-wide resources needed to take, make, ship, and account for customer orders.

The objective of an ERP system is to coordinate a firm's whole business, from supplier evaluation to customer invoicing. This objective is seldom achieved, but ERP systems are evolving as 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 also include:

LO7: 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.

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



▶ **FIGURE 14.11**
MRP and ERP Information Flows, Showing Customer Relationship Management (CRM), Supply-Chain Management (SCM), and Finance/Accounting
Other functions such as human resources are often also included in ERP systems.

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: The Wall Street Journal (April 10, 2007): B1; *Frontline Solutions* (April 2003): 54; and *MIT Sloan Management Review* (Fall 2001): 46–53.

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 the 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, CMS Software (all of the U.S.), sell software or modules designed for specific industries (a set of SAP's modules is shown in Figure 14.12). 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 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.

▼ FIGURE 14.12 **SAP's Modules for ERP**

CASH TO CASH
Covers all financial related activity:
Accounts receivable · **General ledger** · **Cash management**
Accounts payable · **Treasury** · **Asset management**

PROMOTE TO DELIVER
Covers front-end customer-oriented activities:
Marketing
Quote and order processing
Transportation
Documentation and labeling
After sales service
Warranty and guarantees

DESIGN TO MANUFACTURE
Covers internal production activities:
Design engineering · **Shop floor reporting**
Production engineering · **Contract/project management**
Plant maintenance · **Subcontractor management**

RECRUIT TO RETIRE
Covers all HR- and payroll-oriented activity:
Time and attendance · **Payroll**
Travel and expenses

PROCURE TO PAY
Covers sourcing activities:
Vendor sourcing
Purchase requisitioning
Purchase ordering
Purchase contracts
Inbound logistics
Supplier invoicing/matching
Supplier payment/settlement
Supplier performance

DOCK TO DISPATCH
Covers internal inventory management:
Warehousing · **Forecasting** · **Physical inventory**
Distribution planning · **Replenishment planning** · **Material handling**

Source: www.sap.com.

Advantages and Disadvantages of ERP Systems

We have alluded to some of the pluses and minuses of ERP. Here is a more complete list of both.

Advantages:

1. Provides integration of the supply chain, production, and administrative process.
2. Creates commonality of databases.
3. Can incorporate improved, reengineered, "best processes."
4. Increases communication and collaboration among business units and sites.
5. Has a software database that is off-the-shelf coding.
6. May provide a strategic advantage over competitors.

Disadvantages:

1. Is very expensive to purchase, and even more costly to customize.
2. Implementation may require major changes in the company and its processes.
3. Is so complex that many companies cannot adjust to it.
4. Involves an ongoing process for implementation, which may never be completed.
5. Expertise in ERP is limited, with staffing an ongoing problem.

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. As is the case in manufacturing, **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.

CHAPTER 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.

Production should often be lot-for-lot in an MRP system. 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.

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. 578)
Master production schedule (MPS) (p. 578)
Bill of material (BOM) (p. 580)
Modular bills (p. 582)
Planning bills (or kits) (p. 582)
Phantom bills of material (p. 582)
Low-level coding (p. 582)
Lead time (p. 583)
Gross material requirements plan (p. 584)
Net material requirements (p. 585)
Planned order receipt (p. 585)
Planned order release (p. 585)
System nervousness (p. 588)
Time fences (p. 588)
Pegging (p. 588)
Buckets (p. 588)
Bucketless system (p. 589)
Back flush (p. 589)
Supermarket (p. 589)
Lot-sizing decision (p. 589)
Lot-for-lot (p. 589)
Part period balancing (PPB) (p. 591)
Economic part period (EPP) (p. 592)
Wagner-Whitin procedure (p. 593)
Material requirements planning II (MRP II) (p. 593)
Closed-loop MRP system (p. 594)
Load report (p. 595)
Distribution resource planning (DRP) (p. 596)
Enterprise resource planning (ERP) (p. 597)
Efficient consumer response (ECR) (p. 600)

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 very structure of MRP systems suggests fixed lead times. However, many firms have moved toward JIT and kanban techniques. What are the techniques, issues, and impact of adding JIT inventory and purchasing techniques to an organization that has MRP?

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.

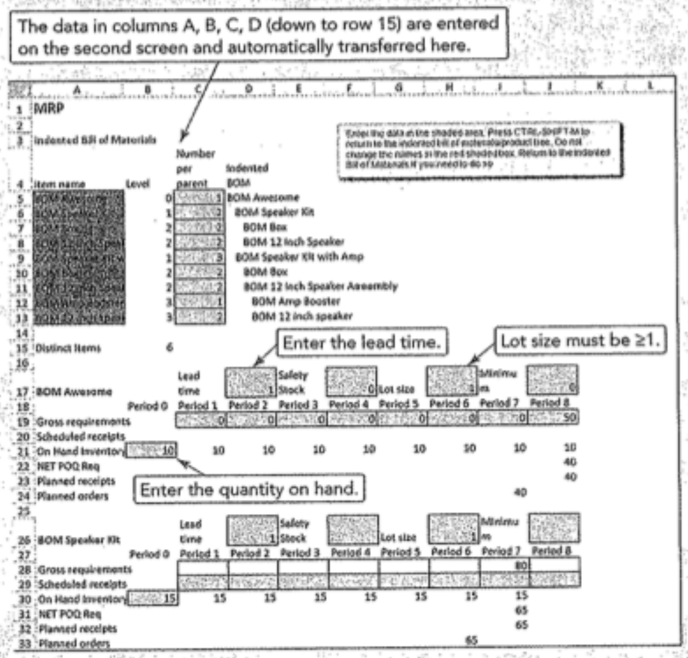
Using Excel OM

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 (i.e., Item no., Part), (3) total number of periods to be scheduled, and (4) what we want the periods called (i.e., 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 (i.e., 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.

▶ PROGRAM 14.1
Using Excel OM's MRP Module to Solve 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.)

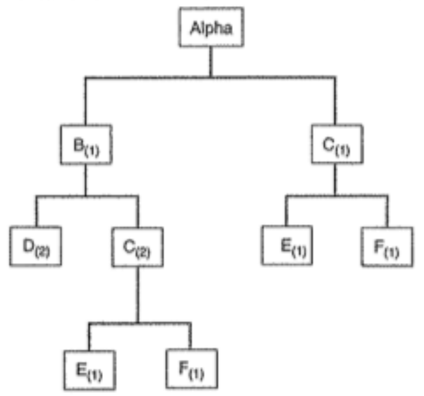
Further details regarding POM for Windows are seen in Appendix IV.

Solved Problems

Virtual Office Hours help is available at www.pearsonglobaleditions.com/myomlab

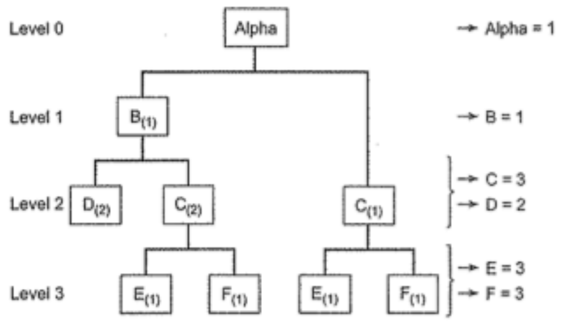
▶ SOLVED PROBLEM 14.1

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:

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

and Es required for right branch:

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

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.

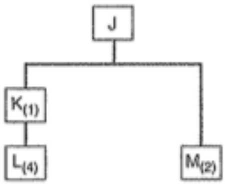
Lot Size	Lead Time (# of Periods)	On Hand	Safety Stock	Allo-cated	Low-Level Code	Item ID			1	2	3	4	5	6	7	8	9	10	11	12	13
Lot-for-Lot	1	10	—	—	0	Alpha (A)	Gross Requirements									50			50		100
							Scheduled Receipts														
							Projected On Hand	10								10					
							Net Requirements									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

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

Problems*

• **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** 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.

•• **14.4** Using the information in Problem 14.3, construct a gross material requirements plan. P/X

•• **14.5** Using the information in Problem 14.3, construct a net material requirements plan using the following on-hand inventory.

*Note: P/X 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 14.23 through 14.27) 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 is available at **www.usersolutions.com**.

Lot Size	Lead Time (# of periods)	On Hand	Safety Stock	Allo-cated	Low-Level Code	Item ID		Period (week, day) 1	2	3	4	5	6	7	8
							Gross Requirements								
							Scheduled Receipts								
							Projected On Hand								
							Net Requirements								
							Planned Order Receipts								
							Planned Order Releases								
							Gross Requirements								
							Scheduled Receipts								
							Projected On Hand								
							Net Requirements								
							Planned Order Receipts								
							Planned Order Releases								
							Gross Requirements								
							Scheduled Receipts								
							Projected On Hand								
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							Scheduled Receipts								
							Projected On Hand								
							Net Requirements								
							Planned Order Receipts								
							Planned Order Releases								
							Gross Requirements								
							Scheduled Receipts								
							Projected On Hand								
							Net Requirements								
							Planned Order Receipts								
							Planned Order Releases								

▲ FIGURE 14.13 MRP Form for Homework Problems in Chapter 14
For several problems in this chapter, a copy of this form may be helpful.

Item	On-Hand Inventory	Item	On-Hand Inventory
S	20	W	30
T	20	X	25
U	40	Y	240
V	30	Z	40

•• **14.6** Refer again to Problems 14.3 and 14.4. 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.

•• **14.7** Refer again to Problems 14.3 and 14.5. 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.

•• **14.8** As the production planner for Gerry Cook 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.

•• **14.9** Your boss at Gerry Cook Products, Inc., has just provided you with the schedule and lead times for the bracket in Problem 14.8. 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?

•• **14.10**

a) Given the product structure and master production schedule (Figure 14.14 below), develop a gross requirements plan for all items.
b) Given the preceding product structure, master production schedule, and inventory status (Figure 14.14), develop a net materials requirements (planned order release) for all items.

••• **14.11** Given the following product structure, master production schedule, and inventory status (Figure 14.15 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 14.15, 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

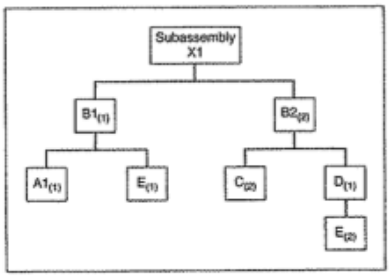
••• **14.14** A part structure, lead time (weeks), and on-hand quantities for product A are shown in Figure 14.16. From the information shown, generate

▼ FIGURE 14.14 **Information for Problem 14.10**

Master Production Schedule for X1

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

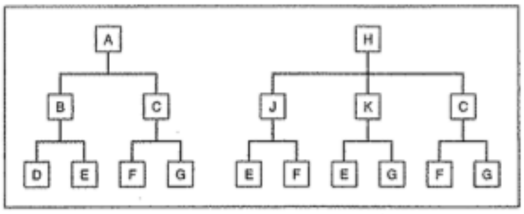
ITEM	LEAD TIME	ON HAND	ITEM	LEAD TIME	ON HAND
X1	1	50	C	1	0
B1	2	20	D	1	0
B2	2	20	E	3	10
A1	1	5			



▶ FIGURE 14.15
Information for Problems 14.11 and 14.12

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



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. PX

••• **14.15** You are product planner for product A (in Problem 14.14 and Figure 14.16). 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. PX

••• **14.16** You have just been notified via fax that the lead time for component G of product A (Problem 14.15 and Figure 14.16) 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

Data Table for Problems 14.17 through 14.19*

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.

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

••• **14.18** Develop an EOQ solution and calculate total relevant costs for the data in the preceding table. Stockout costs equal $10 per unit. PX

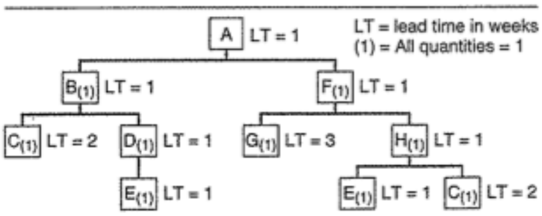
••• **14.19** Develop a PPB solution and calculate total relevant costs for the data in the preceding table. PX

••• **14.20** Using the gross requirements schedule in Examples 4, 5, and 6 in the text, prepare an alternative ordering system that always orders 100 units the week prior to a shortage (a fixed order quantity of 100) with the same costs as in the example (setup at $100 each, holding at $1 per unit per period). What is the cost of this ordering system? PX

▶ FIGURE 14.16
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



••• **14.21** Using the gross requirements schedule in Examples 4, 5, and 6 in the text, prepare an alternative ordering system that orders every 3 weeks for 3 weeks ahead (a periodic order quantity). Use the same costs as in the example (setup at $100 each, holding at $1 per unit per period). What is the cost of this ordering system?

••• **14.22** Using the gross requirements schedule in Examples 4, 5, and 6 in the text, prepare an alternative ordering system of your own design that uses the same cost as in the example (setup at $100 each, holding at $1 per unit per period). Can you do better than the costs shown in the text? What is the cost of your ordering system?

••• **14.23** Katharine Hepburn, 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.

••• **14.24** David Jurman, 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

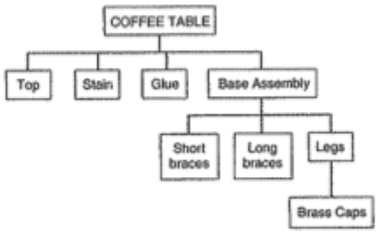
The entire fabrication for these units is scheduled on one machine. There are 2,250 usable minutes in a week, and each unit will take 65 minutes to complete. Develop a capacity plan, using lot splitting, for the 10-week time period.

•• **14.25** 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.

••••**14.26** You are scheduling production of your popular Rustic Coffee Table. 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. You have 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.



•••• **14.27** Using the data for the coffee table in Problem 14.26, 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?

Refer to myomlab for these additional homework problems: 14.28–14.32

Case Studies

Hill's Automotive, Inc.

Hill's Automotive, Inc., is an aftermarket producer and distributor of automotive replacement parts. Art Hill has slowly expanded the business, which began as a supplier of hard-to-get auto air-conditioning units for classic cars and hot rods. The firm has limited manufacturing capability, but a state-of-the-art MRP system and extensive inventory and assembly facilities. Components are purchased, assembled, and repackaged. Among its products are private-label air-conditioning, carburetors, and ignition kits. The downturn in the economy, particularly the company's discretionary segment, has put downward pressure on volume and margins. Profits have fallen considerably. In addition, customer service levels have declined, with late deliveries now exceeding 25% of orders. And to make matters worse, customer returns have been rising at a rate of 3% per month.

Wally Hopp, vice president of sales, claims that most of the problem lies with the assembly department. He says that although the firm has accurate bills of materials, indicating what goes into each product, it is not producing the proper mix of the product. He also believes the firm has poor quality control and low productivity, and as a result its costs are too high.

Melanie Thompson, treasurer, believes that problems are due to investing in the wrong inventories. She thinks that marketing has too many options and products. Melanie also thinks that purchasing department buyers have been hedging their inventories and requirements with excess purchasing commitments.

The assembly manager, Kalinga Jagoda, says, "The symptom is that we have a lot of parts in inventory, but no place to assemble them in the production schedule. When we have the right part, it is not very good, but we use it anyway to meet the schedule."

Marshall Fisher, manager of purchasing, has taken the stance that purchasing has not let Hill's Automotive down. He has stuck by his old suppliers, used historical data to determine requirements, maintained what he views as excellent prices from suppliers, and evaluated new sources of supply with a view toward lowering cost. Where possible, Marshall reacted to the increased pressure for profitability by emphasizing low cost and early delivery.

Discussion Question

1. Prepare a plan for Art Hill that gets the firm back on a course toward improved profitability. Be sure to identify the symptoms, the problems, and the specific changes you would implement.
2. Explain how MRP plays a role in this plan.

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 Study: Visit **www.pearsonglobaleditions.com/myomlab** or **www.pearsonglobaleditions.com/heizer** for this free case study:

Ikon's attempt at ERP: The giant office technology firm faces hurdles with ERP implementation.

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Chapter 14 Rapid Review

Main Heading	Review Material	myomlab
DEPENDENT DEMAND (p. 578)	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.	**VIDEO 14.1** MRP at Wheeled Coach Ambulances
DEPENDENT INVENTORY MODEL REQUIREMENTS (pp. 578–583)	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)**—A material grouping 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*.	Problems: 14.1, 14.3 Virtual Office Hours for Solved Problem: 14.1
MRP STRUCTURE (pp. 583–587)	■ **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)	Problems: 14.2, 14.4–14.8 Virtual Office Hours for Solved Problem: 14.2 **ACTIVE MODEL 14.1**
MRP MANAGEMENT (pp. 588–589)	■ **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. ■ **Bucketless system**—Time-phased data are referenced using dated records rather than defined time periods, or buckets. ■ **Back flush**—A system to reduce inventory balances by deducting everything in the bill of material on completion of the unit. ■ **Supermarket**—An inventory area that holds common items that are replenished by a kanban system.	
LOT-SIZING TECHNIQUES (pp. 589–593)	■ **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. ■ **Part period balancing (PPB)**—An inventory ordering technique that balances setup and holding costs by changing the lot size to reflect requirements of the next lot size in the future.	Problems: 14.17–14.22

Main Heading	Review Material
	■ **Economic part period (EPP)**—A period of time when the ratio of setup cost to holding cost is equal. ■ **Wagner-Whitin procedure**—A technique for lot-size computation that assumes a finite time horizon beyond which there are no additional net requirements to arrive at an ordering strategy. In general, the lot-for-lot approach should be used whenever low-cost deliveries can be achieved.
EXTENSIONS OF MRP (pp. 593–596)	■ **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*, or, *lot splitting*.
MRP IN SERVICES (pp. 596–597)	■ **Distribution resource planning (DRP)**—A time-phased stock-replenishment plan for all levels of a distribution network.
ENTERPRISE RESOURCE PLANNING (ERP) (p. 597–600)	■ **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.

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.

LO1. 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.

LO2. 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.

LO3. 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.

LO4. A lot-sizing procedure that assumes a finite time horizon beyond which there are no additional net requirements is:
- **a)** Wagner-Whitin algorithm.
- **b)** part period balancing.
- **c)** economic order quantity.
- **d)** all of the above.

LO5. MRP II stands for:
- **a)** material resource planning.
- **b)** management requirements planning.
- **c)** management resource planning.
- **d)** material revenue planning.
- **e)** material risk planning.

LO6. 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

LO7. 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: LO1. c; LO2. c; LO3. d; LO4. a; LO5. a; LO6. b; LO7. d.