

# Material Requirements Planning (MRP) and ERP

# 14

CHAPTER

## CHAPTER OUTLINE

### GLOBAL COMPANY PROFILE: *Wheeled Coach*

- ◆ Dependent Demand **566**
- ◆ Dependent Inventory Model Requirements **566**
- ◆ MRP Structure **571**
- ◆ MRP Management **575**
- ◆ Lot-Sizing Techniques **576**
- ◆ Extensions of MRP **580**
- ◆ MRP in Services **583**
- ◆ Enterprise Resource Planning (ERP) **584**



Alaska Airlines

- Design of Goods and Services
- Managing Quality
- Process Strategy
- Location Strategies
- Layout Strategies
- Human Resources
- Supply-Chain Management

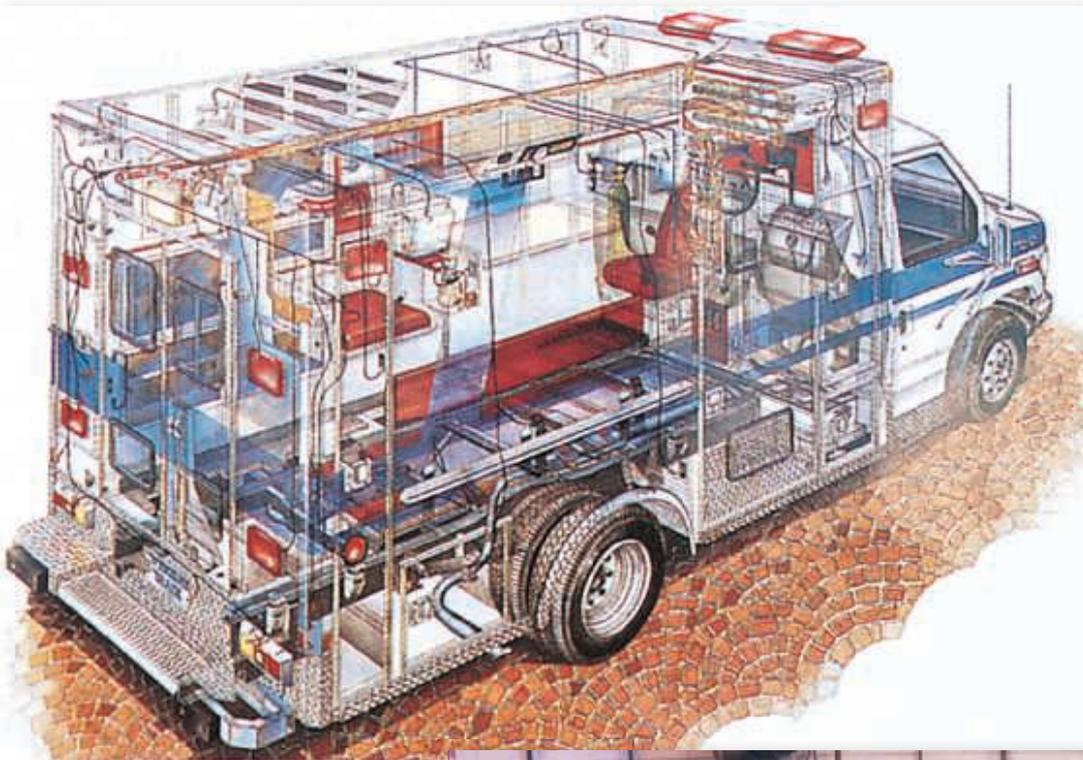
- *Inventory Management*
  - Independent Demand (Ch. 12)
  - **Dependent Demand (Ch. 14)**
  - Lean Operations (Ch. 16)
- Scheduling
- Maintenance

**GLOBAL COMPANY PROFILE**

*Wheeled Coach*

# MRP Provides a Competitive Advantage for Wheeled Coach

**W**heeled 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



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

Wheeled Coach Industries Incorporated

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



Wheeled Coach Industries Incorporated

## LEARNING OBJECTIVES

- LO 14.1** *Develop* a product structure 569
- LO 14.2** *Build* a gross requirements plan 572
- LO 14.3** *Build* a net requirements plan 573
- LO 14.4** *Determine* lot sizes for lot-for-lot, EOQ, and POQ 577
- LO 14.5** *Describe* MRP II 580
- LO 14.6** *Describe* closed-loop MRP 582
- LO 14.7** *Describe* ERP 584

## Dependent Demand

### STUDENT TIP

“Dependent demand” means the demand for one item is related to the demand for another item.

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

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

When the requirements of MRP are met, dependent models are preferable to the models for independent demand (EOQ) described in Chapter 12.<sup>1</sup> 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.

### 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.

## Dependent Inventory Model Requirements

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

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

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

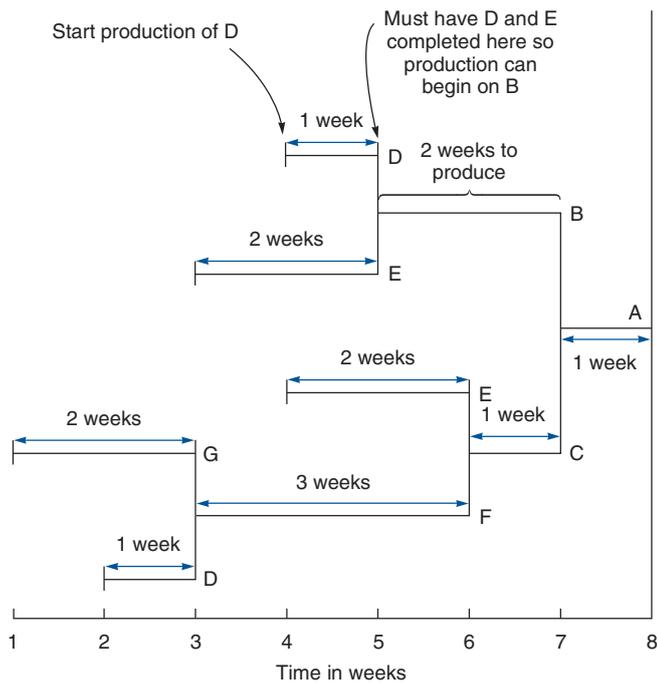


Figure 14.3

**Time-Phased Product Structure**

**STUDENT TIP**

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

## MRP Structure

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

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

**Gross material requirements plan**

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

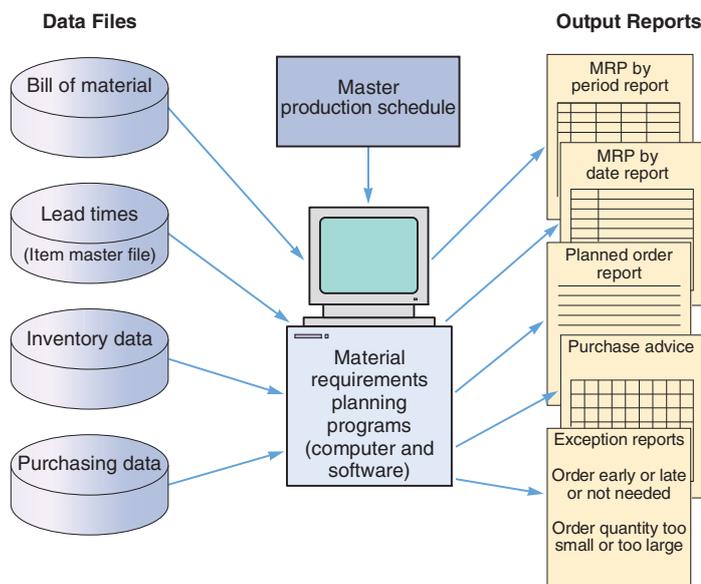


Figure 14.4

**Structure of the MRP System**

**STUDENT TIP**

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

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	0		
							Net Requirements												90
							Planned Order Receipts												90
							Planned Order Releases											90	

Figure 14.6  
Sample MRP Planning Sheet for Item Z

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

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

## MRP Management

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

### MRP Dynamics

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

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

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

### MRP Limitations

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

#### 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.

**Buckets**

Time units in a material requirements planning system.

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

## Lot-Sizing Techniques

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

**Lot-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.

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

### Example 4

#### LOT SIZING WITH LOT-FOR-LOT

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

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

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

**MRP Lot Sizing: Lot-for-Lot Technique\***

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

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

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

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

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

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

material purchase lots (for example, a truckload of chemicals may be available in only one lot size). However, caution should be exercised prior to any modification of lot size because the modification can cause substantial distortion of actual requirements at lower levels in the MRP hierarchy. When setup costs are significant and demand is reasonably smooth, POQ or even EOQ should provide satisfactory results. Too much concern with lot sizing yields false accuracy because of MRP dynamics. A correct lot size can be determined only after the fact, based on what actually happened in terms of requirements.

## Extensions of MRP

In this section, we review three extensions of MRP.

### Material Requirements Planning II (MRP II)

#### Material requirements planning II (MRP II)

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

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

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

#### LO 14.5 Describe MRP II



Jim Convis, User Solutions, Inc.

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

A demo program is available for student use at

[www.usersolutions.com](http://www.usersolutions.com).

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

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

**RELATED PROBLEMS** ▶ 14.29, 14.30

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

## MRP in Services

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

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

(a) **PRODUCT STRUCTURE TREE**

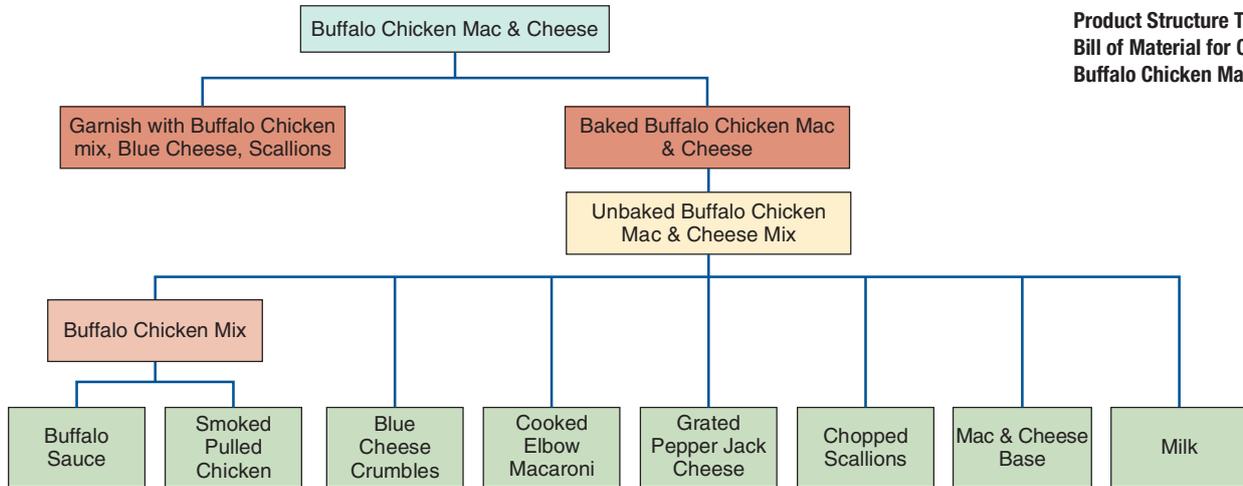


Figure 14.9

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

(b) **BILL OF MATERIALS**

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

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

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

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

## Distribution Resource Planning (DRP)

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

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.

### Distribution resource planning (DRP)

A time-phased stock-replenishment plan for all levels of a distribution network.

## Enterprise Resource Planning (ERP)

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

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

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

### 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.

### LO 14.7 Describe ERP

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

## ERP in the Service Sector

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

### Efficient consumer response (ECR)

Supply chain management systems in the grocery industry that tie sales to buying, to inventory, to logistics, and to production.

## Summary

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

When properly implemented, MRP can contribute in a major way to reduction in inventory while improving customer service levels. MRP techniques allow the operations manager to schedule and replenish stock on a “need-to-order” basis rather than simply a “time-to-order” basis.

Many firms using MRP systems find that lot-for-lot can be the low-cost lot-sizing option.

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

## Key Terms

Material requirements planning (MRP) (p. 566)	Gross material requirements plan (p. 571)	Periodic order quantity (POQ) (p. 578)
Master production schedule (MPS) (p. 567)	Net requirements plan (p. 572)	Material requirements planning II (MRP II) (p. 580)
Bill of material (BOM) (p. 568)	Planned order receipt (p. 574)	Closed-loop MRP system (p. 581)
Modular bills (p. 569)	Planned order release (p. 574)	Load report (p. 581)
Planning bills (or kits) (p. 570)	System nervousness (p. 575)	Distribution resource planning (DRP) (p. 584)
Phantom bills of material (p. 570)	Time fences (p. 575)	Enterprise resource planning (ERP) (p. 584)
Low-level coding (p. 570)	Pegging (p. 575)	Efficient consumer response (ECR) (p. 587)
Lead time (p. 570)	Buckets (p. 576)	
	Lot-sizing decision (p. 576)	
	Lot-for-lot (p. 576)	

## Ethical Dilemma

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

The accounting, human resource, supply chain, and marketing teams put together by the client have reviewed the specifications

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

What do you do?

## Discussion Questions

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

## Using Software to Solve MRP Problems

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

### ✕ USING EXCEL OM

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

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

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

### P USING POM FOR WINDOWS

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

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

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

Program 14.1

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

The data in columns A, B, C, D (down to row 15) are entered on the second screen and automatically transferred here.

Enter the lead time. Lot size must be  $\geq 1$ .

Enter the quantity on hand.

Item	Level	Number per parent	Indented BOM
BOM Awesome (A)	0	1	BOM Awesome (A)
B	1	1	B
C	1	1	C
D	2	2	D
E	2	2	E
F	2	2	F
G	3	1	G
H	3	2	H

Item	Lead time	Safety Stock	Lot size	Minimum
BOM Awesome	1	0	1	0
BOM Speaker Kit	1	0	1	0

Item	Period 0	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8
Gross requirements	0	0	0	0	0	0	0	0	50
Scheduled receipts									
On Hand Inventory	10	10	13	10	10	10	10	10	10
NET POQ Req									48
Planned receipts									40
Planned orders									65

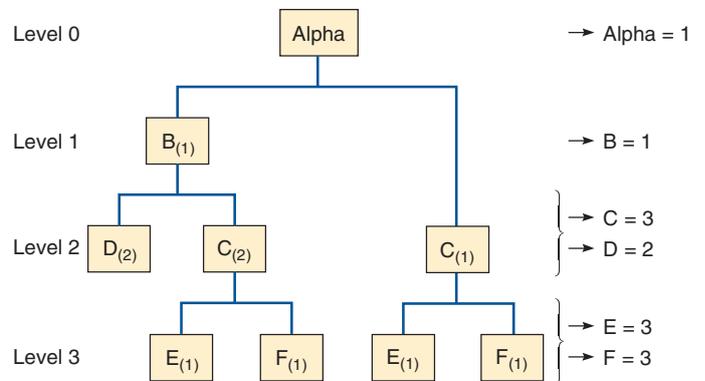
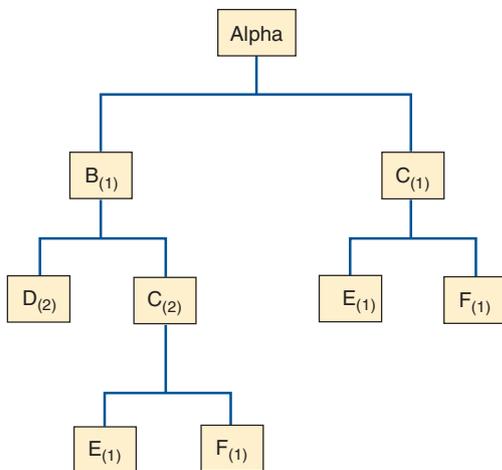
Solved Problems Virtual Office Hours help is available in MyOMLab.

SOLVED PROBLEM 14.1

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

SOLUTION

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



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

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

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

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

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

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

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

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

Holding cost = 15 units × \$2 = \$30

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

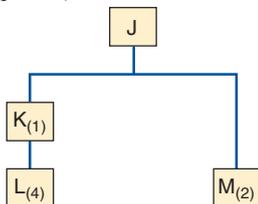
Total cost for POQ lot sizing = \$30 + \$150 = \$180

Problems\*

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

Problems 14.1–14.4 relate to **Dependent Inventory Model Requirements**

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



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

• **14.3** As the production planner for Xiangling Hu Products, Inc., you have been given a bill of material for a bracket that is

made up of a base, two springs, and four clamps. The base is assembled from one clamp and two housings. Each clamp has one handle and one casting. Each housing has two bearings and one shaft. There is no inventory on hand.

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

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

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

Problems 14.5–14.21 relate to **MRP Structure**

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

Additional problem 14.28 is available in MyOMLab.

**Problems 14.29–14.32 relate to Extensions of MRP**

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

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

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

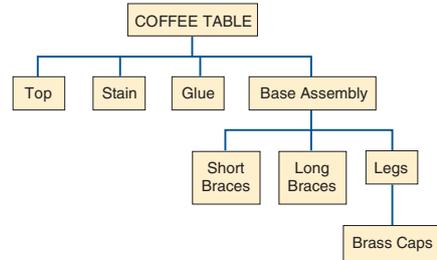
••• **14.30** Coleman Rich, Ltd., has received the following orders:

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

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

••• **14.31** Courtney Kamauf schedules production of a popular Rustic Coffee Table at Kamauf Enterprises, Inc. The table requires a

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



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

## CASE STUDIES

### When 18,500 Orlando Magic Fans Come to Dinner



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

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

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

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

**Production Specifications**

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

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

### Discussion Questions\*

1. Prepare a bill of material explosion and total cost for the 216 portions of Cheeto Crusted Mac & Cheese.

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

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

## MRP at Wheeled Coach

## Video Case

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

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

The discovery of this excess inventory led to renewed efforts to ensure that the BOMs were accurate. With substantial work,

BOM accuracy increased and the number of engineering change notices (ECNs) decreased. Similarly, purchase-order accuracy, with regard to both part numbers and quantities ordered, was improved. Additionally, receiving department and stockroom accuracy went up, all helping to maintain schedule, costs, and ultimately, shipping dates and quality.

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

### Discussion Questions\*

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

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

- **Additional Case Studies:** Visit [MyOMLab](#) for these free case studies:

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

**Hill's Automotive, Inc.:** An after-market producer and distributor of auto replacement parts has trouble making MRP work.

## Endnotes

1. The inventory models (EOQ) discussed in Chapter 12 assumed that the demand for one item was independent of the demand for another item. For example, EOQ assumes the demand for refrigerator parts is *independent* of the demand for refrigerators and that demand for parts is constant. MRP makes neither of these assumptions.
2. Record accuracy of 99% may sound good, but note that even when each component has an availability of 99% and a product

has only seven components, the likelihood of a product being completed is only .932 (because  $.99^7 = .932$ ).

3. Using EOQ is a convenient approach for determining the time between orders, but other rules can be used.
4. *Part period balancing*, *Silver-Meal*, and *Wagner-Whitin* are included in the software POM for Windows and ExcelOM, available with this text.

# Chapter 14 *Rapid Review*

Main Heading	Review Material	MyOMLab
<b>DEPENDENT DEMAND</b> (p. 566)	<p>Demand for items is <i>dependent</i> when the relationship between the items can be determined. For any product, all components of that product are dependent demand items.</p> <ul style="list-style-type: none"> <li>■ <b>Material requirements planning (MRP)</b>—A dependent demand technique that uses a bill-of-material, inventory, expected receipts, and a master production schedule to determine material requirements.</li> </ul>	Concept Questions: 1.1–1.4
<b>DEPENDENT INVENTORY MODEL REQUIREMENTS</b> (pp. 566–571)	<p>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.</p> <ul style="list-style-type: none"> <li>■ <b>Master production schedule (MPS)</b>—A timetable that specifies what is to be made and when.</li> </ul> <p>The MPS is a statement of <i>what is to be produced</i>, not a forecast of demand.</p> <ul style="list-style-type: none"> <li>■ <b>Bill of material (BOM)</b>—A listing of the components, their description, and the quantity of each required to make one unit of a product.</li> </ul> <p>Items above any level in a BOM are called <i>parents</i>; items below any level are called <i>components</i>, or <i>children</i>. The top level in a BOM is the 0 level.</p> <ul style="list-style-type: none"> <li>■ <b>Modular bills</b>—Bills of material organized by major subassemblies or by product options.</li> <li>■ <b>Planning bills (or kits)</b>—Material groupings created in order to assign an artificial parent to a bill of material; also called “pseudo” bills.</li> <li>■ <b>Phantom bills of material</b>—Bills of material for components, usually subassemblies, that exist only temporarily; they are never inventoried.</li> <li>■ <b>Low-level coding</b>—A number that identifies items at the lowest level at which they occur.</li> <li>■ <b>Lead time</b>—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.</li> </ul> <p>When a bill of material is turned on its side and modified by adding lead times for each component, it is called a <i>time-phased product structure</i>.</p>	Concept Questions: 2.1–2.4 Problems: 14.1–14.4 Virtual Office Hours for Solved Problem: 14.1
<b>MRP STRUCTURE</b> (pp. 571–575)	<ul style="list-style-type: none"> <li>■ <b>Gross material requirements plan</b>—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.</li> <li>■ <b>Net material requirements</b>—The result of adjusting gross requirements for inventory on hand and scheduled receipts.</li> <li>■ <b>Planned order receipt</b>—The quantity planned to be received at a future date.</li> <li>■ <b>Planned order release</b>—The scheduled date for an order to be released.</li> </ul> <p>Net requirements = Gross requirements + Allocations – (On hand + Scheduled receipts)</p>	Concept Questions: 3.1–3.4 Problems: 14.5–14.9, 14.11, 14.16–14.21 Virtual Office Hours for Solved Problem: 14.2
<b>MRP MANAGEMENT</b> (pp. 575–576)	<ul style="list-style-type: none"> <li>■ <b>System nervousness</b>—Frequent changes in an MRP system.</li> <li>■ <b>Time fences</b>—A means for allowing a segment of the master schedule to be designated as “not to be rescheduled.”</li> <li>■ <b>Pegging</b>—In material requirements planning systems, tracing upward the bill of material from the component to the parent item.</li> </ul> <p>Four approaches for integrating MRP and JIT are (1) finite capacity scheduling, (2) small buckets, (3) balanced flow, and (4) supermarkets.</p> <ul style="list-style-type: none"> <li>■ <b>Buckets</b>—Time units in a material requirements planning system.</li> </ul> <p>Finite capacity scheduling (FCS) considers department and machine capacity. FCS provides the precise scheduling needed for rapid material movement.</p>	Concept Questions: 4.1–4.4
<b>LOT-SIZING TECHNIQUES</b> (pp. 576–580)	<ul style="list-style-type: none"> <li>■ <b>Lot-sizing decision</b>—The process of, or techniques used in, determining lot size.</li> <li>■ <b>Lot-for-lot</b>—A lot-sizing technique that generates exactly what is required to meet the plan.</li> <li>■ <b>Periodic order quantity (POQ)</b>—A lot-sizing technique that issues orders on a predetermined time interval with an order quantity equal to all of the interval’s requirements.</li> </ul> <p>In general, the lot-for-lot approach should be used whenever low-cost deliveries setup can be achieved.</p>	Concept Questions: 5.1–5.4 Problems: 14.22, 14.26, 14.28

Main Heading	Review Material	
<b>EXTENSIONS OF MRP</b> (pp. 580–583)	<ul style="list-style-type: none"> <li>■ <b>Material requirements planning II (MRP II)</b>—A system that allows, with MRP in place, inventory data to be augmented by other resource variables; in this case, MRP becomes <i>material resource planning</i>.</li> <li>■ <b>Closed-loop MRP system</b>—A system that provides feedback to the capacity plan, master production schedule, and production plan so planning can be kept valid at all times.</li> <li>■ <b>Load report</b>—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: <i>overlapping</i>, <i>operations splitting</i>, and <i>order splitting</i>, or <i>lot splitting</i>.</li> </ul>	Concept Questions: 6.1–6.4 Problem: 14.32
<b>MRP IN SERVICES</b> (pp. 583–584)	<ul style="list-style-type: none"> <li>■ <b>Distribution resource planning (DRP)</b>—A time-phased stock-replenishment plan for all levels of a distribution network.</li> </ul>	Concept Questions: 7.1–7.4
<b>ENTERPRISE RESOURCE PLANNING (ERP)</b> (pp. 584–587)	<ul style="list-style-type: none"> <li>■ <b>Enterprise resource planning (ERP)</b>—An information system for identifying and planning the enterprise-wide resources needed to take, make, ship, and account for customer orders.</li> </ul> <p>In an ERP system, data are entered only once into a common, complete, and consistent database shared by all applications.</p> <ul style="list-style-type: none"> <li>■ <b>Efficient consumer response (ECR)</b>—Supply-chain management systems in the grocery industry that tie sales to buying, to inventory, to logistics, and to production.</li> </ul>	Concept Questions: 8.1–8.4

## Self Test

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

- LO 14.1** In a product structure diagram:
- parents are found only at the top level of the diagram.
  - parents are found at every level in the diagram.
  - children are found at every level of the diagram except the top level.
  - all items in the diagrams are both parents and children.
  - all of the above.
- LO 14.2** The difference between a gross material requirements plan (gross MRP) and a net material requirements plan (net MRP) is:
- the gross MRP may not be computerized, but the net MRP must be computerized.
  - the gross MRP includes consideration of the inventory on hand, whereas the net MRP doesn't include the inventory consideration.
  - the net MRP includes consideration of the inventory on hand, whereas the gross MRP doesn't include the inventory consideration.
  - the gross MRP doesn't take taxes into account, whereas the net MRP includes the tax considerations.
  - the net MRP is only an estimate, whereas the gross MRP is used for actual production scheduling.
- LO 14.3** Net requirements =
- Gross requirements + Allocations – On-hand inventory + Scheduled receipts.
  - Gross requirements – Allocations – On-hand inventory – Scheduled receipts.
  - Gross requirements – Allocations – On-hand inventory + Scheduled receipts.
  - Gross requirements + Allocations – On-hand inventory – Scheduled receipts.
- LO 14.4** A lot-sizing procedure that orders on a predetermined time interval with the order quantity equal to the total of the interval's requirement is:
- periodic order quantity.
  - part period balancing.
  - economic order quantity.
  - all of the above.
- LO 14.5** MRP II stands for:
- material resource planning.
  - management requirements planning.
  - management resource planning.
  - material revenue planning.
  - material risk planning.
- LO 14.6** A(n) \_\_\_\_\_ MRP system provides information to the capacity plan, to the master production schedule, and ultimately to the production plan.
- dynamic
  - closed-loop
  - continuous
  - retrospective
  - introspective
- LO 14.7** Which system extends MRP II to tie in customers and suppliers?
- MRP III
  - JIT
  - IRP
  - ERP
  - Enhanced MRP II

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