

Material Requirements Planning (MRP) and ERP

14

CHAPTER

CHAPTER OUTLINE

GLOBAL COMPANY PROFILE: *Wheeled Coach*

- ◆ Dependent Demand **566**
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Alaska Airlines

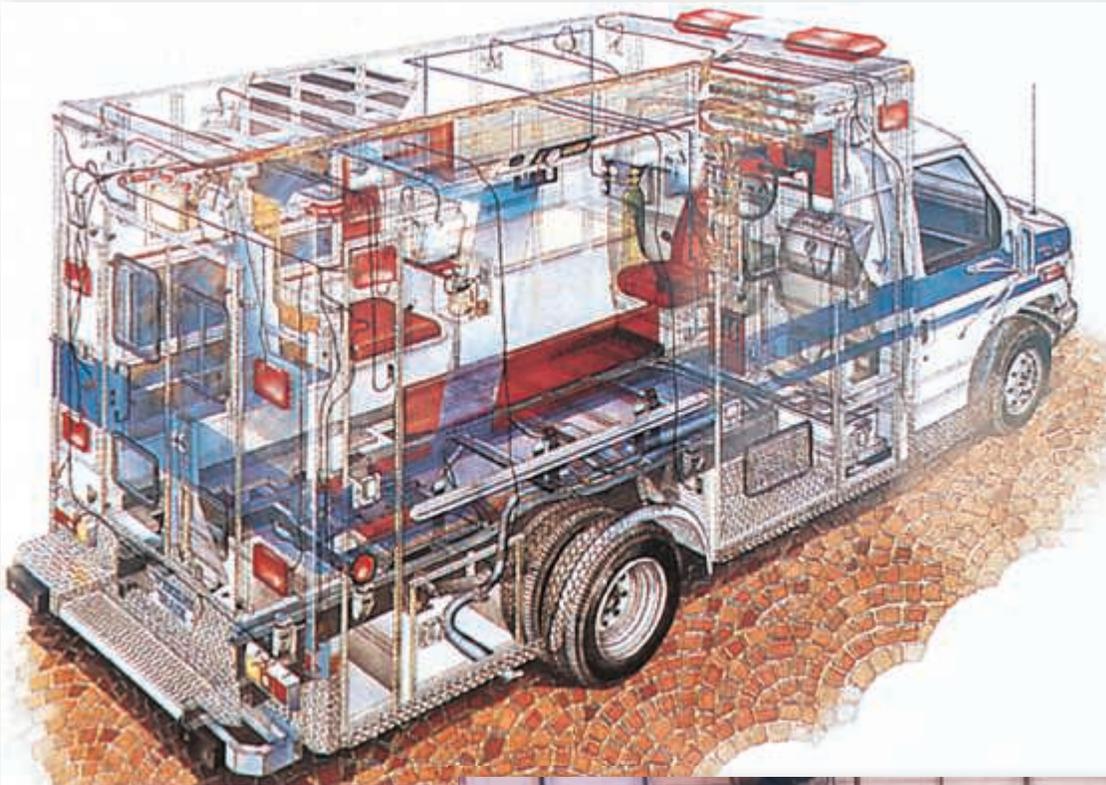
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STRATEGY
DECISIONS

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

GLOBAL COMPANY PROFILE
Wheeled Coach

MRP Provides a Competitive Advantage for Wheeled Coach

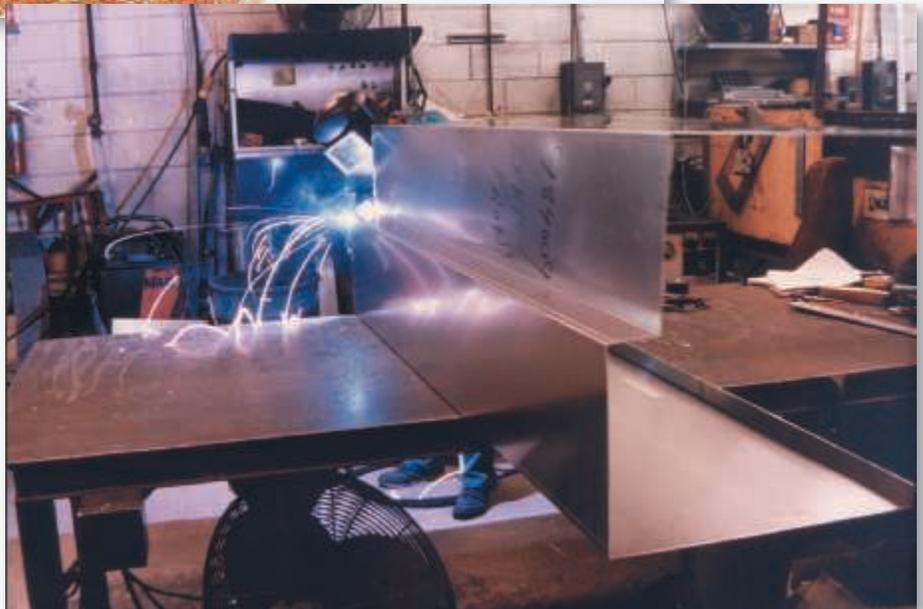
Wheeled Coach, headquartered in Winter Park, Florida, is the largest manufacturer of ambulances in the world. The \$200 million firm is an international competitor that sells more than 25% of its vehicles to markets outside the U.S. Twelve major ambulance designs are produced on assembly lines (i.e.,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



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

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

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

Wheeled Coach insists that four key tasks be performed properly. First, the material plan must meet both the requirements of the master schedule and the capabilities of the

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

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



Wheeled Coach Industries Incorporated

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



Wheeled Coach Industries Incorporated

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

LEARNING OBJECTIVES

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Dependent Demand

STUDENT TIP

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

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

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

When the requirements of MRP are met, dependent models are preferable to the models for independent demand (EOQ) described in Chapter 12.¹ Dependent models are better not only for manufacturers and distributors but also for a wide variety of firms from restaurants to hospitals. The dependent technique used in a production environment is called **material requirements planning (MRP)**.

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.

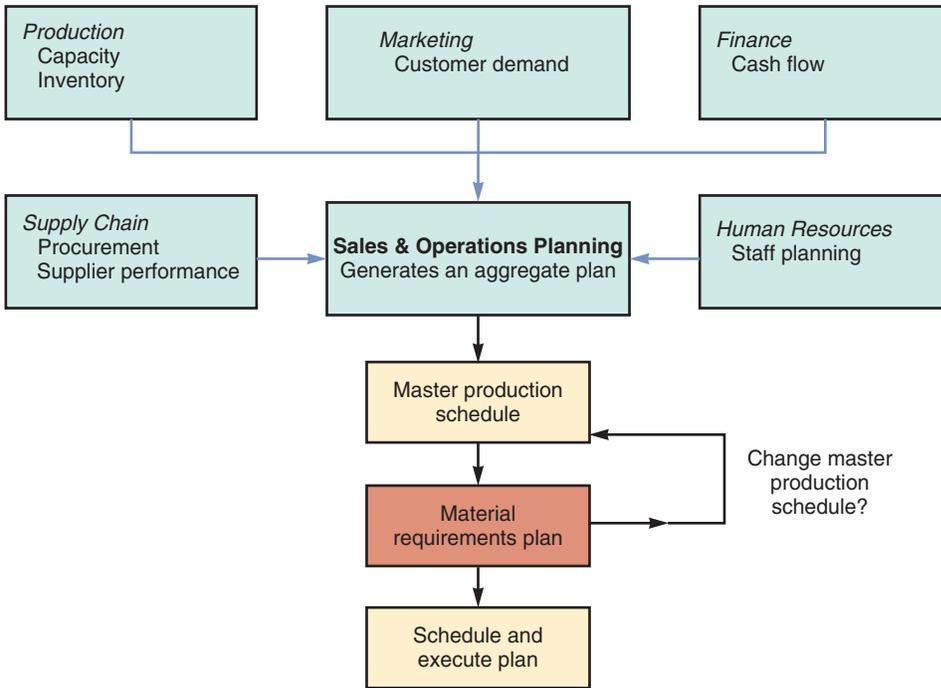


Figure 14.1
The Planning Process

Master Production Schedule

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

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

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

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

Aggregate Plan
(Shows the total quantity of amplifiers)

Months	January				February			
	1,500				1,200			
Weeks	1	2	3	4	5	6	7	8
240-watt amplifier	100		100		100		100	
150-watt amplifier		500		500		450		450
75-watt amplifier			300				100	

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

Figure 14.2

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

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

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

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

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

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

Bills of Material

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

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.

VIDEO 14.1

When 18,500 Orlando Magic Fans Come to Dinner

Bill of material (BOM)

A listing of the components, their description, and the quantity of each required to make one unit of a product.

VIDEO 14.2

MRP at Wheeled Coach Ambulances

Example 1

DEVELOPING A PRODUCT STRUCTURE AND GROSS REQUIREMENTS

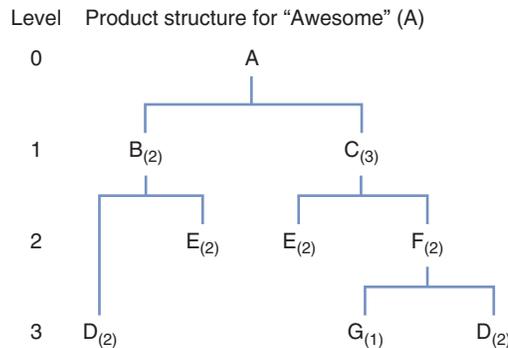
Speaker Kits, Inc., packages high-fidelity components for mail order. Components for the top-of-the-line speaker kit, “Awesome” (A), include 2 Bs and 3 Cs.

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

LO 14.1 Develop a product structure

APPROACH ► Given the preceding information, we construct a product structure and “explode” the requirements.

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



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:	$2 \times \text{number of As} =$	$(2)(50) =$	100
Part C:	$3 \times \text{number of As} =$	$(3)(50) =$	150
Part D:	$2 \times \text{number of Bs} + 2 \times \text{number of Fs} =$	$(2)(100) + (2)(300) =$	800
Part E:	$2 \times \text{number of Bs} + 2 \times \text{number of Cs} =$	$(2)(100) + (2)(150) =$	500
Part F:	$2 \times \text{number of Cs} =$	$(2)(150) =$	300
Part G:	$1 \times \text{number of Fs} =$	$(1)(300) =$	300

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

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

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

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

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

Modular bills

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

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

Planning bills (or kits)

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

Phantom bills of material

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

Low-level coding

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

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

Accurate Inventory Records

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

Purchase Orders Outstanding

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

Lead Times for Components

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

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

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.

TABLE 14.2

Lead Times for Awesome Speaker Kits (As)

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

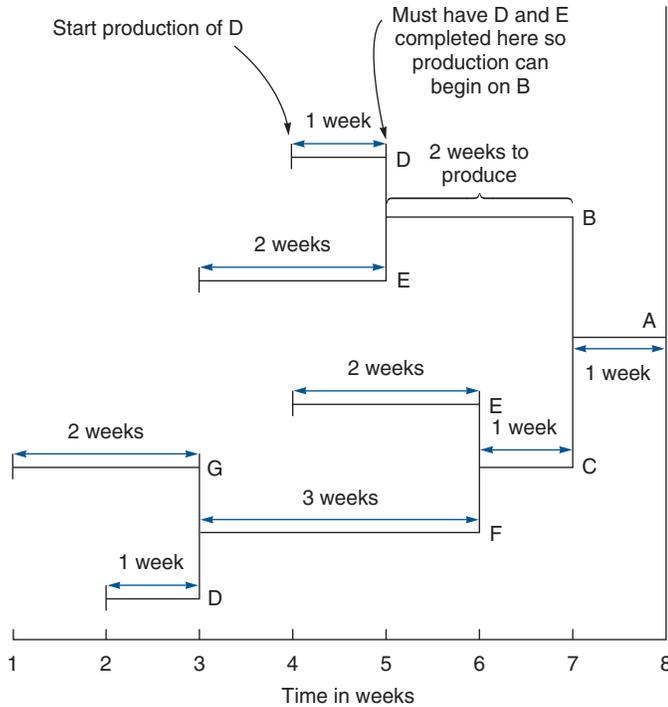


Figure 14.3

Time-Phased Product Structure

STUDENT TIP

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

MRP Structure

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

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

Gross material requirements plan

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

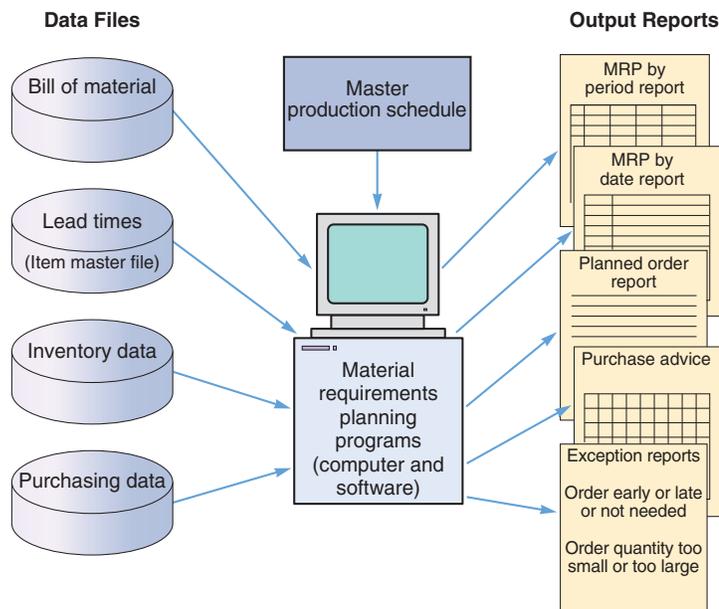


Figure 14.4

Structure of the MRP System

STUDENT TIP

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

Example 2

BUILDING A GROSS REQUIREMENTS PLAN

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

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

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

TABLE 14.3

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

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

LO 14.2 Build a gross requirements plan

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

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

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

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

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

Net requirements plan

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

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

Example 3

DETERMINING NET REQUIREMENTS

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

LO 14.3 Build a net requirements plan

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

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

Lot Size	Lead Time (weeks)	On Hand	Safety Stock	Allocated	Low-Level Code	Item Identification	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	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	20
							Net Requirements									100
							Planned Order Receipts									100
							Planned Order Releases								100	
Lot-for-Lot	2	10	—	—	2	E	Gross Requirements								130 ^B	
							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	5	
							Net Requirements									195
							Planned Order Receipts									195
							Planned Order Releases						195			
Lot-for-Lot	1	10	—	—	3	D	Gross Requirements								390 ^F	
							Scheduled Receipts									
							Projected On Hand	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			

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

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

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

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

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

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

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

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

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.

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

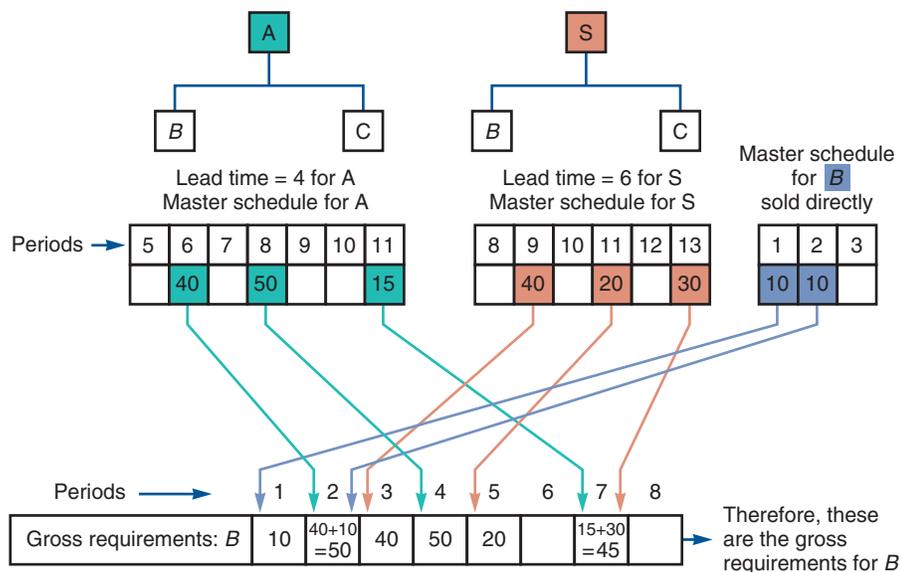
Examples 2 and 3 considered only product A, the Awesome speaker kit, and its completion only in week 8. Fifty units of A were required in week 8. Normally, however, there is a demand for many products over time. For each product, management must prepare a master production schedule (as we saw earlier,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

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

Figure 14.5

Several Schedules Contributing to a Gross Requirements Schedule for B

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



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

Figure 14.6
Sample MRP Planning Sheet for Item Z

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

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

MRP Management

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

MRP Dynamics

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

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

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

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)



John Russell/AP Images

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

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

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

Example 5

LOT SIZING WITH EOQ

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

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

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

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

where D = annual usage = 1,404
 S = setup cost = \$100
 H = holding (carrying) cost, on an annual basis per unit
 = \$1 × 52 weeks = \$52

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

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

MRP Lot Sizing: EOQ Technique*

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

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

For the 10-week planning period:

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

Ordering cost = 4 \times \$100 = \$400

Total = \$375 + \$400 = \$775

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

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

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

Periodic order quantity (POQ)

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

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

Example 6

LOT SIZING WITH POQ

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

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

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

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

Therefore:

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

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

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

MRP Lot Sizing: POQ Technique*

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

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

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

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

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

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

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

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

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

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

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

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

In general, the lot-for-lot approach should be used whenever low-cost setup can be achieved. Lot-for-lot is the goal. Lots can be modified as necessary for scrap allowances, process constraints (for example, a heat-treating process may require a lot of a given size), or raw

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

Extensions of MRP

In this section, we review three extensions of MRP.

Material Requirements Planning II (MRP II)

Material requirements planning II (MRP II)

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

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.

TABLE 14.4 Material Resource Planning (MRP II)

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

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

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

Closed-Loop MRP

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

Closed-loop MRP system

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

Capacity Planning

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

Load report

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

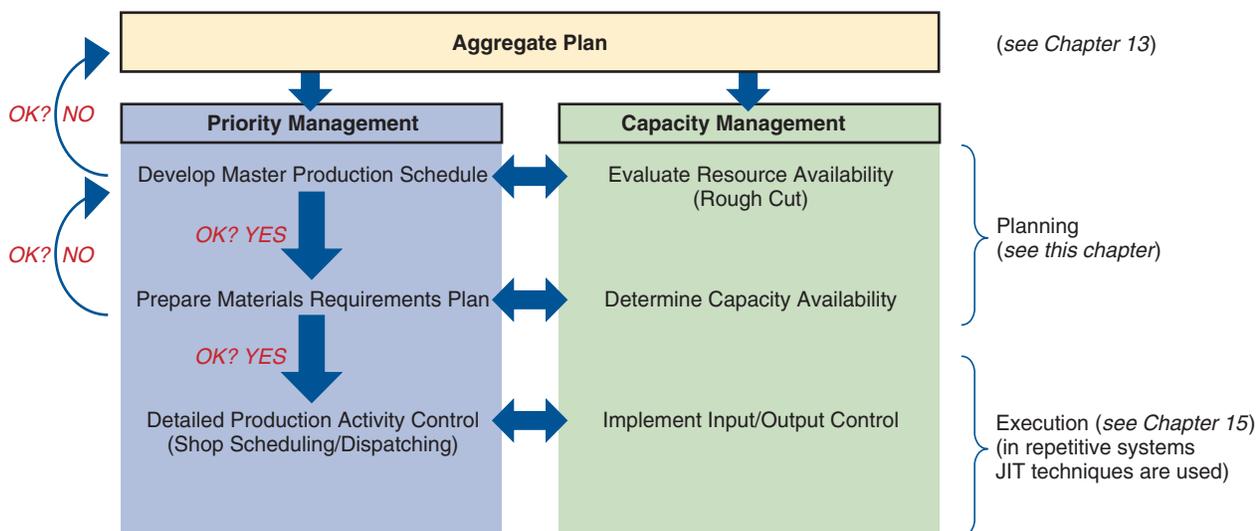
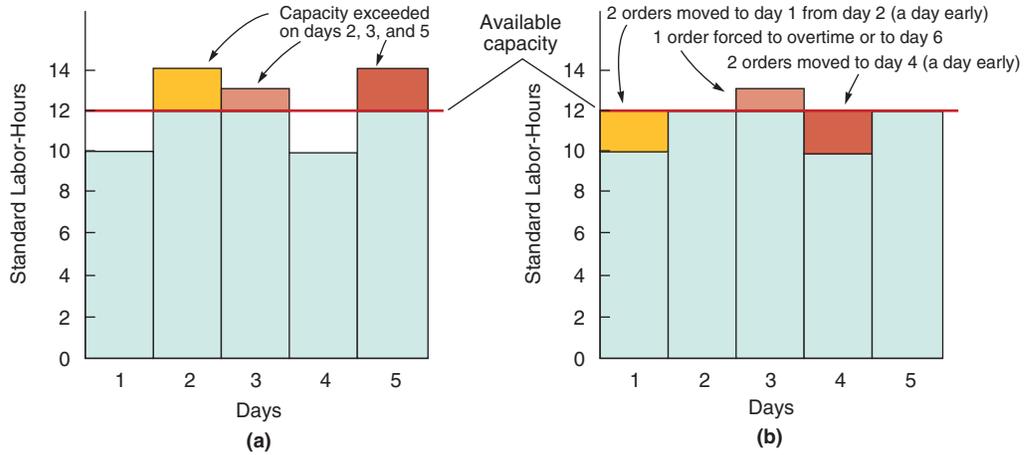


Figure 14.7

Closed-Loop Material Requirements Planning

Figure 14.8

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



LO 14.6 Describe closed-loop MRP

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

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

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

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

Example 7

ORDER SPLITTING

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

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

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

SOLUTION ►

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

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

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

RELATED PROBLEMS ▶ 14.29, 14.30

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

MRP in Services

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

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

(a) **PRODUCT STRUCTURE TREE**

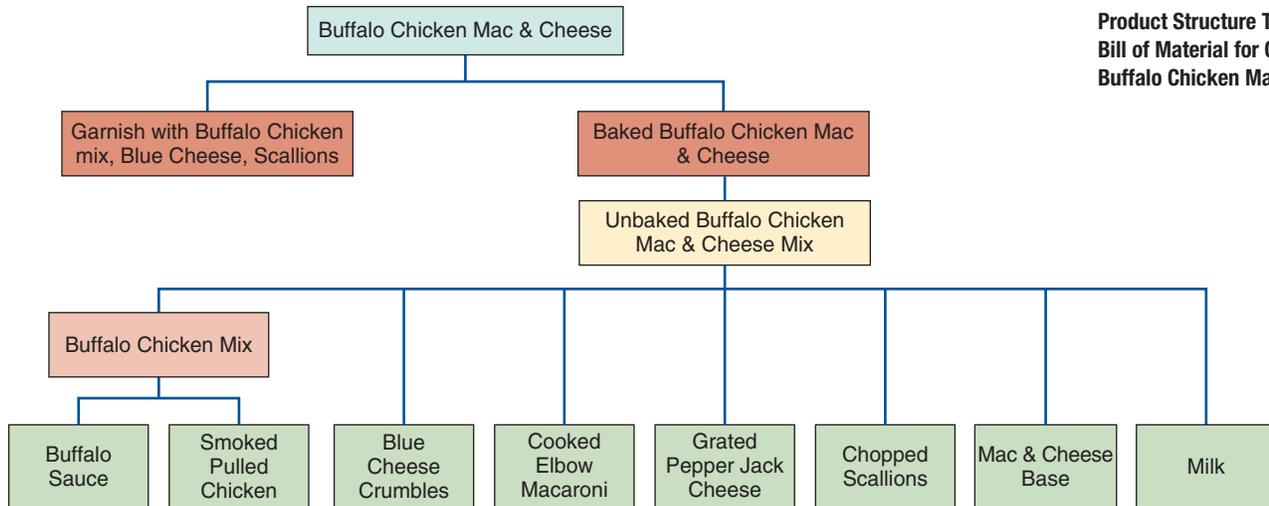


Figure 14.9

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.

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.

Distribution resource planning (DRP)

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

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

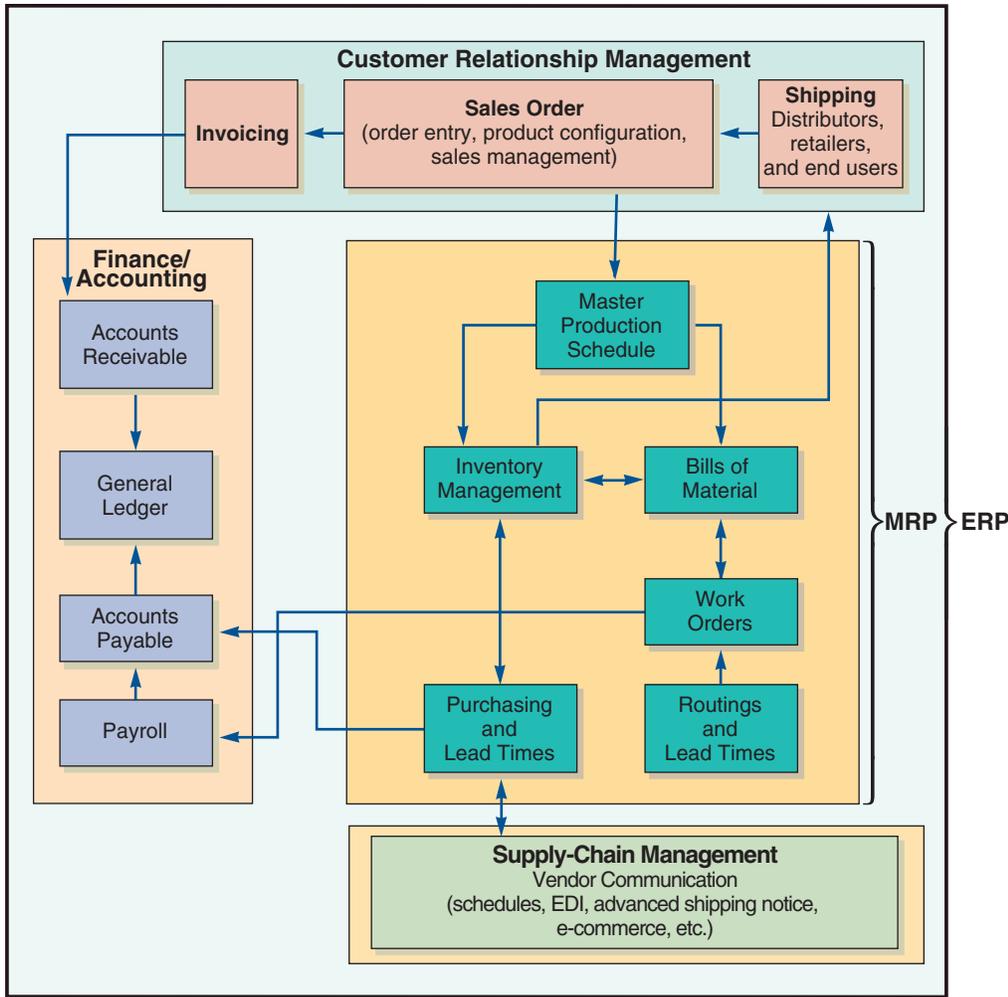


Figure 14.10

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

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

STUDENT TIP

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

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

OM in Action Managing Benetton with ERP Software

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

Here is how ERP software works:

1. **Ordering:** A salesperson in the south Boston store finds that she is running out of a best-selling blue sweater. Using a laptop PC, her local Benetton sales agent taps into the ERP sales module.
2. **Availability:** ERP's inventory software simultaneously forwards the order to the mainframe in Italy and finds that half the order can be filled immediately from the Italian warehouse. The rest will be manufactured and shipped in 4 weeks.

3. **Production:** Because the blue sweater was originally created by computer-aided design (CAD), ERP manufacturing software passes the specifications to a knitting machine. The knitting machine makes the sweaters.
4. **Warehousing:** The blue sweaters are boxed with a radio frequency ID (RFID) tag addressed to the Boston store and placed in one of the 300,000 slots in the Italian warehouse. A robot flies by, reading RFID tags, picks out any and all boxes ready for the Boston store, and loads them for shipment.
5. **Order tracking:** The Boston salesperson logs onto the ERP system through the Internet and sees that the sweater (and other items) are completed and being shipped.
6. **Planning:** Based on data from ERP's forecasting and financial modules, Benetton's chief buyer decides that blue sweaters are in high demand and quite profitable. She decides to add three new hues.

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

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

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

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

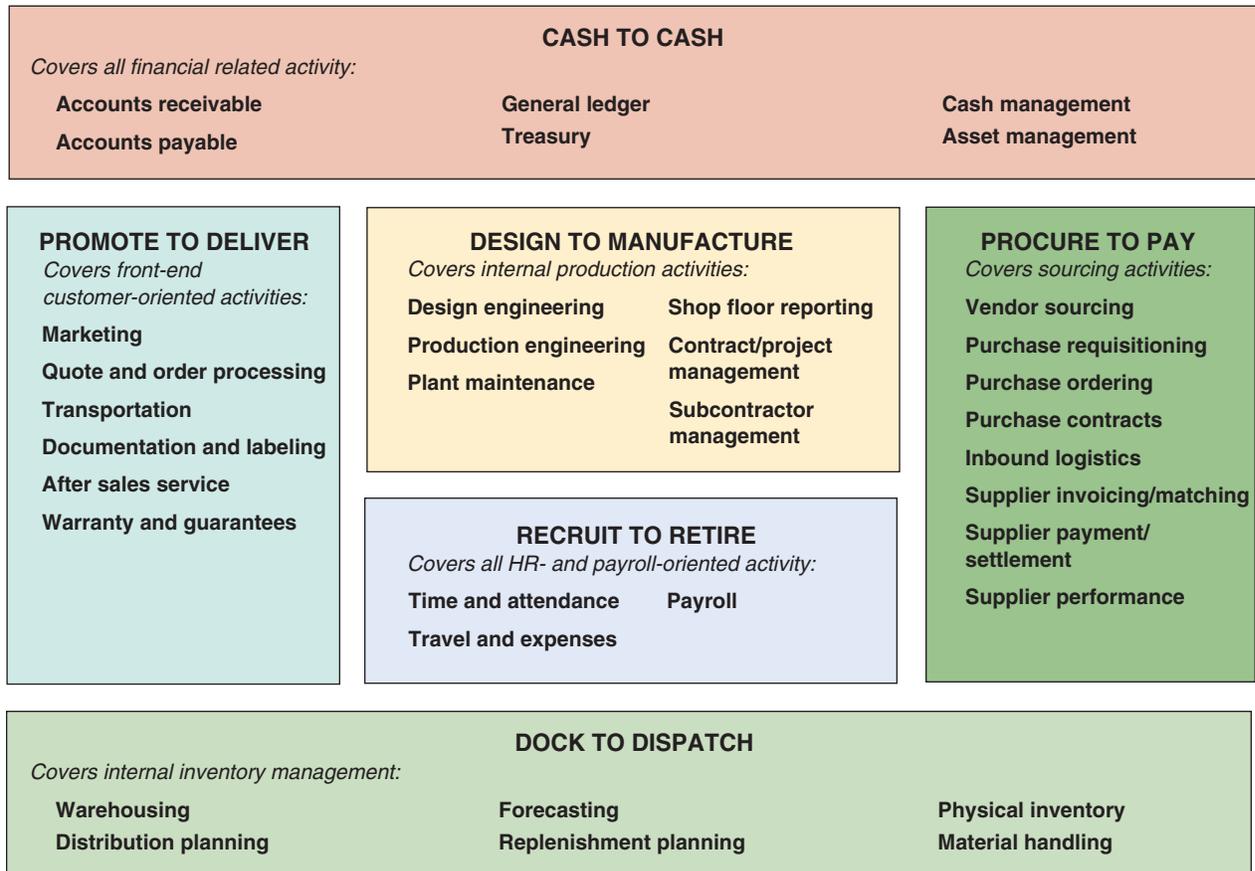


Figure 14.11

SAP’s Modules for ERP

Source: www.sap.com.

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

ERP in the Service Sector

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

Efficient consumer response (ECR)

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

Summary

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

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

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

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

Key Terms

Material requirements planning (MRP) (p. 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, 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 ≥ 1 .

Enter the quantity on hand.

Item	Level	Quantity	Parent	BOM
BOM Awesome (A)	0	1		BOM Awesome (A)
B	1	2	A	B
C	1	3	A	C
D	2	2	B	D
E	2	2	B	E
F	2	2	C	F
G	3	1	C	G
H	3	2	C	H

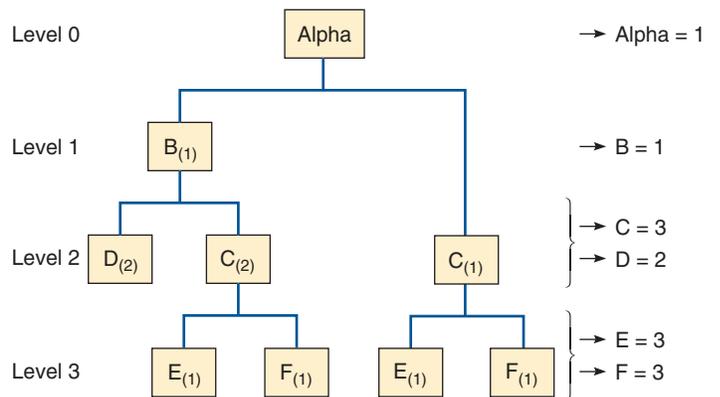
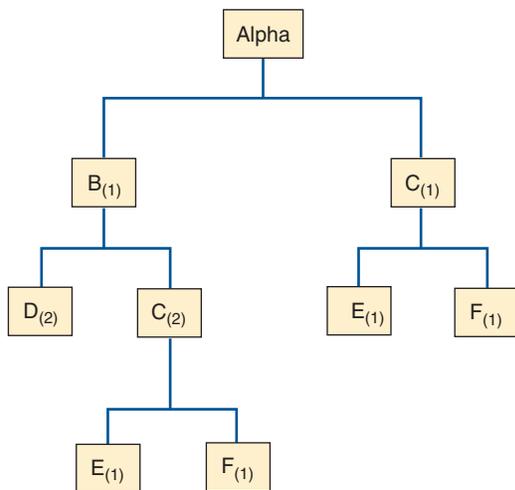
Solved Problems Virtual Office Hours help is available in MyOMLab.

SOLVED PROBLEM 14.1

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

SOLUTION

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



Es required for left branch:

$$(I_{\text{alpha}} \times I_B \times 2_C \times I_E) = 2 \text{ Es}$$

and Es required for right branch:

$$(I_{\text{alpha}} \times I_C \times I_E) = \frac{1 \text{ E}}{3 \text{ Es required in total}}$$

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

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

SOLVED PROBLEM 14.2

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

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

Master Production Schedule for Alpha

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

SOLUTION

See the chart on following page.

SOLVED PROBLEM 14.3

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

SOLUTION

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

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

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

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

SOLVED PROBLEM 14.4

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

(annual demand) = 1,040 units. From Chapter 12, the EOQ model is:

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

where D = annual demand = 1,040

S = Setup cost = \$50

H = holding (carrying) cost, on an annual basis per unit = \$2 × 52 = \$104

$Q^* = 31.62 \approx 32$ units (order the EOQ or in multiples of the EOQ)

SOLUTION

a) For the **EOQ** lot size, first determine the EOQ. Annual usage = 200 units for 10 weeks; weekly usage = 200/10 weeks = 20 per week. Therefore, 20 units × 52 weeks

(Continued on page 592)

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

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

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

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

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

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

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

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

Holding cost = 15 units × \$2 = \$30

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

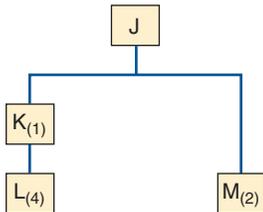
Total cost for POQ lot sizing = \$30 + \$150 = \$180

Problems*

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

Problems 14.1–14.4 relate to Dependent Inventory Model Requirements

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



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

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

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

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

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

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

Problems 14.5–14.21 relate to MRP Structure

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

2 weeks to make U, 2 weeks to make V, 3 weeks to make W, 1 week to make X, 2 weeks to make Y, and 1 week to make Z.

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

b) Prepare a time-phased product structure.

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

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

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

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

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

•• **14.10**

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

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

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

a) develop a gross requirements plan for Item C;

b) develop a net requirements plan for Item C. **Px**

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

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

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

••• **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. **Px**

Data Table for Problem 14.13

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

* Lot-for-lot unless otherwise noted.

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

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

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

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

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

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

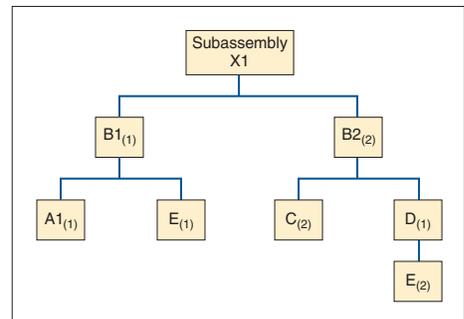
Master Production Schedule for X1

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

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

Figure 14.12

Information for Problem 14.10



PERIOD	8	9	10	11	12
Gross requirements: A	100		50		150
Gross requirements: H		100		50	
ITEM	ON HAND	LEAD TIME	ITEM	ON HAND	LEAD TIME
A	0	1	F	75	2
B	100	2	G	75	1
C	50	2	H	0	1
D	50	1	J	100	2
E	75	2	K	100	2

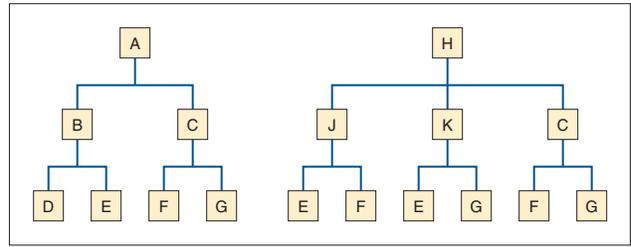


Figure 14.13

Information for Problems 14.11 and 14.12

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

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

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

ITEM	LEAD TIME	ON-HAND INVENTORY	COMPONENTS
Stepper	2	20	A ₍₁₎ , B ₍₃₎ , C ₍₂₎
A	1	10	D ₍₁₎ , F ₍₂₎
B	2	30	E ₍₁₎ , F ₍₃₎
C	3	10	D ₍₂₎ , E ₍₃₎
D	1	15	
E	2	5	
F	2	20	

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

Additional problems 14.18–14.21 are available in MyOMLab.

Problems 14.22–14.28 relate to Lot-Sizing Techniques

Data Table for Problems 14.22 through 14.25*

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

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

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

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

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

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

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

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

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

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

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

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

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

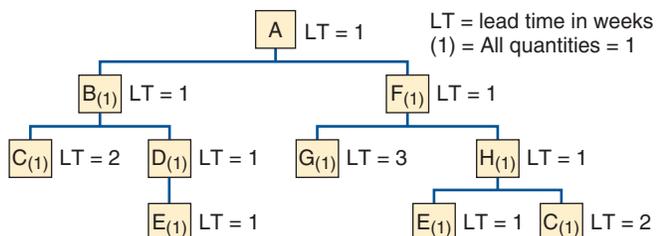
- a) Lot-for-lot.
- b) EOQ.
- c) POQ.
- d) Which plan has the lowest cost? **Px**

Figure 14.14

Information for Problems 14.14, 14.15, and 14.16

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

PART STRUCTURE TREE



Additional problem 14.28 is available in MyOMLab.

Problems 14.29–14.32 relate to Extensions of MRP

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

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

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

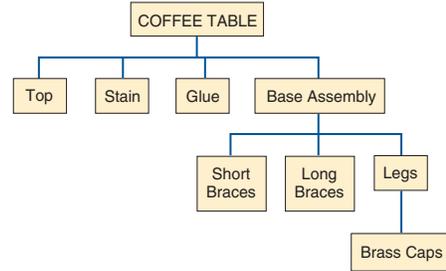
••• **14.30** Coleman Rich, Ltd., has received the following orders:

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

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

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

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



•••• **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
DEPENDENT DEMAND (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"> ■ Material requirements planning (MRP)—A dependent demand technique that uses a bill-of-material, inventory, expected receipts, and a master production schedule to determine material requirements. 	Concept Questions: 1.1–1.4
DEPENDENT INVENTORY MODEL REQUIREMENTS (pp. 566–571)	<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"> ■ Master production schedule (MPS)—A timetable that specifies what is to be made and when. <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"> ■ Bill of material (BOM)—A listing of the components, their description, and the quantity of each required to make one unit of a product. <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"> ■ Modular bills—Bills of material organized by major subassemblies or by product options. ■ Planning bills (or kits)—Material groupings created in order to assign an artificial parent to a bill of material; also called “pseudo” bills. ■ Phantom bills of material—Bills of material for components, usually subassemblies, that exist only temporarily; they are never inventoried. ■ Low-level coding—A number that identifies items at the lowest level at which they occur. ■ Lead time—In purchasing systems, the time between recognition of the need for an order and receiving it; in production systems, it is the order, wait, move, queue, setup, and run times for each component. <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 VIDEO 14.1 When 18,500 Orlando Magic Fans Come to Dinner VIDEO 14.2 MRP at Wheeled Coach Ambulances
MRP STRUCTURE (pp. 571–575)	<ul style="list-style-type: none"> ■ 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. <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 ACTIVE MODEL 14.1
MRP MANAGEMENT (pp. 576–576)	<ul style="list-style-type: none"> ■ 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. <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"> ■ Buckets—Time units in a material requirements planning system. <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
LOT-SIZING TECHNIQUES (pp. 576–580)	<ul style="list-style-type: none"> ■ Lot-sizing decision—The process of, or techniques used in, determining lot size. ■ Lot-for-lot—A lot-sizing technique that generates exactly what is required to meet the plan. ■ Periodic order quantity (POQ)—A lot-sizing technique that issues orders on a predetermined time interval with an order quantity equal to all of the interval’s requirements. <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	
EXTENSIONS OF MRP (pp. 580–583)	<ul style="list-style-type: none"> ▪ 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 <i>material resource planning</i>. ▪ 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: <i>overlapping</i>, <i>operations splitting</i>, and <i>order splitting</i>, or <i>lot splitting</i>. 	Concept Questions: 6.1–6.4 Problem: 14.32
MRP IN SERVICES (pp. 583–584)	<ul style="list-style-type: none"> ▪ Distribution resource planning (DRP)—A time-phased stock-replenishment plan for all levels of a distribution network. 	Concept Questions: 7.1–7.4
ENTERPRISE RESOURCE PLANNING (ERP) (pp. 584–587)	<ul style="list-style-type: none"> ▪ 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. <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"> ▪ Efficient consumer response (ECR)—Supply-chain management systems in the grocery industry that tie sales to buying, to inventory, to logistics, and to production. 	Concept Questions: 8.1–8.4

Self Test

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

- LO 14.1** In a product structure diagram:
- 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.

Short-Term Scheduling

15

CHAPTER

CHAPTER OUTLINE

GLOBAL COMPANY PROFILE: *Alaska Airlines*

- ◆ The Importance of Short-Term Scheduling **602**
- ◆ Scheduling Issues **602**
- ◆ Scheduling Process-Focused Facilities **605**
- ◆ Loading Jobs **605**
- ◆ Sequencing Jobs **611**
- ◆ Finite Capacity Scheduling (FCS) **617**
- ◆ Scheduling Services **618**



Alaska Airlines

- Design of Goods and Services
- Managing Quality
- Process Strategy
- Location Strategies
- Layout Strategies
- Human Resources
- Supply-Chain Management
- Inventory Management
- **Scheduling**
 - Aggregate/S&OP (Ch. 13)
 - **Short-Term (Ch. 15)**
- Maintenance

GLOBAL COMPANY PROFILE
Alaska Airlines

Scheduling Flights When Weather Is the Enemy

Seattle–Tacoma International Airport (SEA) is the 15th busiest in the U.S. in passenger traffic. Served by 24 airlines that fly non-stop to 76 domestic and 19 international destinations, it is a weather forecaster’s nightmare, raining 5 inches a month in the winter season. But it is also the top-ranked U.S. airport in on-time departures, at 85.8%. Much of the credit goes to Alaska Airlines, which dominates traffic at SEA with over 50% of all domestic flights. Alaska’s scheduling is critical to efficiency and passenger service.

4 A.M. FORECAST:
Rain with a chance of light snow for Seattle.

ACTION:
Discuss status of planes and possible need for cancellations.

10 A.M. FORECAST:
Freezing rain after 5 P.M.

ACTION:
Ready deicing trucks; develop plans to cancel 50% to 80% of flights after 6 P.M.

1:30 P.M. FORECAST:
Rain changing to snow.

ACTION:
Cancel half the flights from 6 P.M. to 10 A.M.; notify passengers and reroute planes.

5 P.M. FORECAST:
Less snow than expected.

ACTION:
Continue calling passengers and arrange alternate flights.

10 P.M. FORECAST:
Snow tapering off.

ACTION:
Find hotels for 600 passengers stranded by the storm.

Managers at airlines, such as Alaska, learn to expect the unexpected. Events that require rapid rescheduling are a regular part of life. Throughout the ordeals of hurricanes, tornadoes, ice storms, snow storms, and more, airlines around the globe struggle to cope with delays, cancellations, and furious passengers. The inevitable schedule changes often create a ripple effect that impacts passengers at dozens of airports.



This is typical of what Alaska Air officials had to do one December day when a storm bore down on Seattle.



Alaska Airlines

To improve flight rescheduling efforts, Alaska Air employees monitor numerous screens that display flights in progress, meteorological charts, and weather patterns at its Flight Operations Department in Seattle. Note the many *andon* signal lights used to indicate “status OK” (green), “needs attention” (yellow), or “major issue—emergency” (red).



To maintain schedules, Alaska Airlines uses elaborate equipment and motivated personnel for snow and ice removal.

Alaska Air's quest to provide passenger and freight service to the state of Alaska complicates its scheduling even more than that of other airlines. Here are just three examples: (1) Juneau's airport is surrounded by mountains, so the approach is often buffeted by treacherous wind shears; (2) Sitka's one small runway is on a narrow strip of land surrounded by water; and (3) in Kodiak, the landing strip ends abruptly at a mountainside. The airport approach is so tricky that first officers are not allowed to land there—only captains are trusted to do so.

Alaska Air takes the sting out of the scheduling nightmares that come from weather-related problems by using the latest technology on its planes and in its Flight Operations Department, located near the Seattle airport. From computers to telecommunications systems to deicers, the department reroutes flights, gets its jets in the air, and quickly notifies customers of schedule changes. The department's



Weather-related disruptions can create major scheduling and expensive snow removal issues for airlines (left), just as they create major inconveniences for passengers (right).



job is to keep flights flowing despite the disruptions. Alaska estimates that it saves \$18 million a year by using its technology to reduce cancellations and delays.

With mathematical scheduling models such as the ones described in this text, Alaska quickly develops alternate schedules and route changes. This may mean coordinating incoming and outgoing aircraft, ensuring crews are on hand, and making sure information gets to passengers as soon as possible. Weather may be the enemy, but Alaska Airlines has learned how to manage it. **K**

LEARNING OBJECTIVES

- LO 15.1** *Explain* the relationship between short-term scheduling, capacity planning, aggregate planning, and a master schedule 603
- LO 15.2** *Draw* Gantt loading and scheduling charts 607
- LO 15.3** *Apply* the assignment method for loading jobs 608
- LO 15.4** *Name* and describe each of the priority sequencing rules 613
- LO 15.5** *Use* Johnson's rule 616
- LO 15.6** *Define* finite capacity scheduling 617
- LO 15.7** *Use* the cyclical scheduling technique 620

The Importance of Short-Term Scheduling

Alaska Airlines doesn't just schedule its 150 aircraft every day; it also schedules over 4,500 pilots and flight attendants to accommodate passengers seeking timely arrival at their destinations. This schedule, developed with huge computer programs, plays a major role in meeting customer expectations. Alaska finds competitive advantage with its ability to make last-minute adjustments to demand fluctuations and weather disruptions.

Scheduling decisions for five organizations—an airline, a hospital, a college, a sports arena, and a manufacturer—are shown in Table 15.1. These decisions all deal with the timing of operations.

When manufacturing firms make schedules that match resources to customer demands, scheduling competence focuses on making parts on a just-in-time basis, with low setup times, little work-in-process, and high facility utilization. Efficient scheduling is how manufacturing companies drive down costs and meet promised due dates.

The strategic importance of scheduling is clear:

- ◆ Internally effective scheduling means faster movement of goods and services through a facility and greater use of assets. The result is greater capacity per dollar invested, which translates into lower costs.
- ◆ Externally good scheduling provides faster throughput, added flexibility, and more dependable delivery, improving customer service.

STUDENT TIP

Scheduling decisions range from years, for capacity planning, to minutes/hours/days, called short-term scheduling. This chapter focuses on the latter.

Scheduling Issues

Figure 15.1 shows that a series of decisions affects scheduling. Schedule decisions begin with planning capacity, which defines the facility and equipment resources available (discussed in Supplement 7). **Capacity plans** are usually made over a period of years as new equipment

TABLE 15.1 Scheduling Decisions

ORGANIZATION	MANAGERS SCHEDULE THE FOLLOWING
Alaska Airlines	Maintenance of aircraft Departure timetables Flight crews, catering, gate, and ticketing personnel
Arnold Palmer Hospital	Operating room use Patient admissions Nursing, security, maintenance staffs Outpatient treatments
University of Alabama	Classrooms and audiovisual equipment Student and instructor schedules Graduate and undergraduate courses
Amway Center	Ushers, ticket takers, food servers, security personnel Delivery of fresh foods and meal preparation Orlando Magic games, concerts, arena football
Lockheed Martin factory	Production of goods Purchases of materials Workers

VIDEO 15.1

From the Eagles to the Magic:
Converting the Amway Center

Capacity Planning
 (Long term; years)
 Changes in facilities
 Changes in equipment
 See Chapter 7 and Supplement 7



Aggregate Planning
 (Intermediate term; quarterly or monthly)
 Facility utilization
 Personnel changes
 Subcontracting
 See Chapter 13



Master Schedule
 (Intermediate term; weekly)
 Material requirements planning
 Disaggregate the aggregate plan
 See Chapters 13 and 14



Short-Term Scheduling
 (Short term; days, hours, minutes)
 Work center loading
 Job sequencing/dispatching
 See this chapter

Capacity Plan for New Facilities

Adjust capacity to the demand suggested by strategic plan



Myrleen Pearson/Alamy

Aggregate Production Plan for All Bikes

(Determine personnel or subcontracting necessary to match aggregate demand to existing facilities/capacity)

Month	1	2
Bike Production	800	850

Master Production Schedule for Bike Models

(Determine weekly capacity schedule)

Week	Month 1				Month 2			
	1	2	3	4	5	6	7	8
Model 22		200		200		200		200
Model 24	100		100		150		100	
Model 26	100		100		100		100	

Work Assigned to Specific Personnel and Work Centers

Make finite capacity schedule by matching specific tasks to specific people and machines



Peter Endig/dpa/Landov

Assemble Model 22 in work center 6

Figure 15.1

The Relationship Between Capacity Planning, Aggregate Planning, Master Schedule, and Short-Term Scheduling for a Bike Company

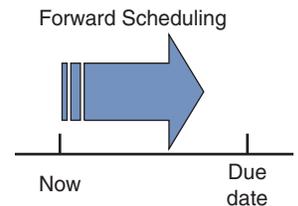
and facilities are designed, built, purchased, or shut down. **Aggregate plans** (Chapter 13) are the result of a Sales and Operating Planning team that makes decisions regarding the use of facilities, inventory, people, and outside contractors. Aggregate plans are typically for 3 to 18 months, and resources are allocated in terms of an aggregate measure such as total units, tons, or shop hours. The **master schedule** breaks down the aggregate plan and develops weekly schedules for specific products or product lines. **Short-term schedules** then translate capacity decisions, aggregate (intermediate) plans, and master schedules into job sequences and specific assignments of personnel, materials, and machinery. In this chapter, we focus on this last step, scheduling goods and services in the *short run* (that is, matching daily or hourly demands to specific personnel and equipment capacity). See the *OM in Action* box “Prepping for the Orlando Magic Basketball Game.”

The objective of scheduling is to allocate and prioritize demand (generated by either forecasts or customer orders) to available facilities. Three factors are pervasive in scheduling: (1) generating the schedule forward or backward, (2) finite and infinite loading, and (3) the criteria (priorities) for sequencing jobs. We discuss these topics next.

Forward and Backward Scheduling

Scheduling can be initiated forward or backward. Forward scheduling starts the schedule *as soon as the job requirements are known*. Forward scheduling is used in organizations such as hospitals, clinics, restaurants, and machine tool manufacturers. In these facilities, jobs are performed to customer order, and delivery is typically scheduled at the earliest possible date.

LO 15.1 Explain the relationship between short-term scheduling, capacity planning, aggregate planning, and a master schedule



OM in Action

Prepping for the Orlando Magic Basketball Game

Tuesday. It's time for John Nicely to make a grocery list. He is serving dinner on Sunday, so he will need a few things . . . 200 pounds of chicken and steak, ingredients for 800 servings of mac 'n' cheese, 500 spring rolls, and 75 pounds of shrimp. Plus a couple hundred pizzas and a couple thousand hot dogs—just enough to feed the Orlando Magic basketball players and the 18,500 guests expected. You see, Nicely is the executive chef of the Amway Center in Orlando, and on Sunday the Magic are hosting the Boston Celtics.

How do you feed huge crowds good food in a short time? It takes good scheduling, combined with creativity and improvisation. With 42 facilities serving food and beverages, “the Amway Center,” Nicely says, “is its own beast.”

Wednesday. Shopping Day.

Thursday–Saturday. The staff prepares whatever it can. Chopping vegetables, marinating meats, mixing salad dressings—everything but cooking the food. Nicely also begins his shopping lists for next Tuesday's game against the Miami Heat and for a Lady Gaga concert 3 days later.

Sunday. 4 P.M. Crunch time. Suddenly the kitchen is a joke-free zone. In 20 minutes, Nicely's first clients, 120 elite ticket holders who belong to the Ritz Carlton Club, expect their meals—from a unique menu created for each game.

5 P.M. As the Magic and Celtics start warming up, the chefs move their operation in a brisk procession of hot boxes and cold-food racks to the satellite kitchens.

6:12 P.M. Nicely faces surprises at three concession stands: a shortage of cashiers and a broken cash register.

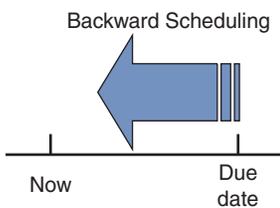
Halftime. There is a run on rice pilaf in the upscale Jernigan's restaurant. But Nicely has thought ahead and has anticipated. The backup dishes arrive before customers even notice.

For Nicely, successful scheduling means happy guests as a result of a thousand details having been identified, planned, and executed. Just another night of delivering restaurant-quality meals and top-grade fast food to a sold-out arena crowd in a span of a few hours.



Fernando Medina

Source: Interview with Chef John Nicely and Orlando Magic executives.



Backward scheduling *begins with the due date*, scheduling the *final* operation first. Steps within the job are then scheduled, one at a time, in reverse order. By subtracting the time needed for each item, the start time is obtained. Backward scheduling is used in manufacturing environments, as well as service environments such as catering a banquet or scheduling surgery. In practice, a combination of forward and backward scheduling is often used to find a reasonable trade-off between capacity constraints and customer expectations.

Finite and Infinite Loading

Loading

The assigning of jobs to work or processing centers.

Loading is the process of assigning jobs to work stations or processes. Scheduling techniques that load (or assign) work only up to the capacity of the process are called *finite loading*. The advantage of finite loading is that, in theory, all of the work assigned can be accomplished. However, because only work that can be accomplished is loaded into workstations—when in fact there may be more work than capacity—the due dates may be pushed out to an unacceptable future time.

Techniques that load work without regard for the capacity of the process are *infinite loading*. All the work that needs to be accomplished in a given time period is assigned. The capacity of the process is not considered. Most material requirements planning (MRP) systems (discussed in Chapter 14) are infinite loading systems. The advantage of infinite loading is an initial schedule that meets due dates. Of course, when the workload exceeds capacity, either the capacity or the schedule must be adjusted.

Scheduling Criteria

The correct scheduling technique depends on the volume of orders, the nature of operations, and the overall complexity of jobs, as well as the importance placed on each of four criteria:

1. *Minimize completion time:* Evaluated by determining the average completion time.
2. *Maximize utilization:* Evaluated by determining the percent of the time the facility is utilized.
3. *Minimize work-in-process (WIP) inventory:* Evaluated by determining the average number of jobs in the system. The relationship between the number of jobs in the system and

TABLE 15.2

Different Processes Suggest Different Approaches to Scheduling

Process-focused facilities (job shops)

- ◆ Scheduling to customer orders where changes in both volume and variety of jobs/clients/patients are frequent.
- ◆ Schedules are often due-date focused, with loading refined by finite loading techniques.
- ◆ *Examples:* foundries, machine shops, cabinet shops, print shops, many restaurants, and the fashion industry.

Repetitive facilities (assembly lines)

- ◆ Schedule module production and product assembly based on frequent forecasts.
- ◆ Finite loading with a focus on generating a forward-looking schedule.
- ◆ JIT techniques are used to schedule components that feed the assembly line.
- ◆ *Examples:* assembly lines for washing machines at Whirlpool and automobiles at Ford.

Product-focused facilities (continuous)

- ◆ Schedule high-volume finished products of limited variety to meet a reasonably stable demand within existing fixed capacity.
- ◆ Finite loading with a focus on generating a forward-looking schedule that can meet known setup and run times for the limited range of products.
- ◆ *Examples:* huge paper machines at International Paper, beer in a brewery at Anheuser-Busch, and potato chips at Frito-Lay.

WIP inventory will be high. Therefore, the fewer the number of jobs that are in the system, the lower the inventory.

4. *Minimize customer waiting time:* Evaluated by determining the average number of late periods (e.g., days or hours).

These four criteria are used in this chapter, as they are in industry, to evaluate scheduling performance. In addition, good scheduling techniques should be simple, clear, easily understood, easy to carry out, flexible, and realistic.

Scheduling is further complicated by machine breakdowns, absenteeism, quality problems, shortages, and other factors. Consequently, assignment of a date does not ensure that the work will be performed according to the schedule. Many specialized techniques have been developed to aid in preparing reliable schedules. Table 15.2 provides an overview of approaches to scheduling for three different processes.

In this chapter, we first examine the scheduling of process-focused facilities and then the challenge of scheduling employees in the service sector.

Scheduling Process-Focused Facilities

Process-focused facilities (also known as *intermittent*, or *job-shop, facilities*) are common in high-variety, low-volume manufacturing and service organizations. These facilities produce make-to-order products or services and include everything from auto repair garages and hospitals to beauty salons. The production items themselves differ considerably, as do the talents, material, and equipment required to make them. Scheduling requires that the sequence of work (its routing), time required for each item, and the capacity and availability of each work center be known. The variety of products and unique requirements means that scheduling is often complex. In this section we look at some of the tools available to managers for loading and sequencing work for these facilities.

Loading Jobs

Operations managers assign jobs to work centers so that costs, idle time, or completion times are kept to a minimum. “Loading” work centers takes two forms. One is oriented to capacity; the second is related to assigning specific jobs to work centers.

First, we examine loading from the perspective of capacity via a technique known as *input–output* control. Then, we present two approaches used for loading: *Gantt charts* and the *assignment method* of linear programming.

Input–Output Control

Many firms have difficulty scheduling (that is, achieving effective throughput) because they overload the production processes. This often occurs because they do not know actual performance in the work centers. Effective scheduling depends on matching the schedule to performance. Lack of knowledge about capacity and performance causes reduced throughput.

Input–output control is a technique that allows operations personnel to manage facility work flows. If the work is arriving faster than it is being processed, the facility is overloaded, and a backlog develops. Overloading causes crowding in the facility, leading to inefficiencies and quality problems. If the work is arriving at a slower rate than jobs are being performed, the facility is underloaded, and the work center may run out of work. Underloading the facility results in idle capacity and wasted resources. Example 1 shows the use of input–output controls.

Input–output control

A system that allows operations personnel to manage facility work flows.

Example 1

INPUT–OUTPUT CONTROL

Bronson Machining, Inc., manufactures driveway security fences and gates. It wants to develop an input–output control report for its welding work center for 5 weeks (weeks 6/6 through 7/4). The planned input is 280 standard hours per week. The actual input is close to this figure, varying between 250 and 285. Output is scheduled at 320 standard hours, which is the assumed capacity. A backlog exists in the work center.

APPROACH ► Bronson uses schedule information to create Figure 15.2, which monitors the workload–capacity relationship at the work center.

Figure 15.2

Input–Output Control

Welding Work Center (In standard hours)						
Week Ending	6/6	6/13	6/20	6/27	7/4	7/11
Planned Input	280	280	280	280	280	
Actual Input	270	250	280	285	280	
Cumulative Deviation	-10	-40	-40	-35		
Planned Output	320	320	320	320		
Actual Output	270	270	270	270		
Cumulative Deviation	-50	-100	-150	-200		
Cumulative Change in Backlog*	0	-20	-10	+5		

*Sum of actual inputs minus sum of actual outputs = cumulative change in backlog

Explanation: 270 input, 270 output, implies 0 change.

Explanation: 250 input, 270 output, implies -20 change. (20 standard hours less work in the work center)

SOLUTION ► The deviations between scheduled input and actual output are shown in Figure 15.2. Actual output (270 hours) is substantially less than planned. Therefore, neither the input plan nor the output plan is being achieved.

INSIGHT ► The backlog of work in this work center has actually increased by 5 hours by week 6/27. This increases work-in-process inventory, complicating the scheduling task and indicating the need for manager action.

LEARNING EXERCISE ► If actual output for the week of 6/27 was 275 (instead of 270), what changes? [Answer: Output cumulative deviation now is -195, and cumulative change in backlog is 0.]

RELATED PROBLEM ► 15.10

ConWIP cards

Cards that control the amount of work in a work center, aiding input–output control.

Input–output control can be maintained by a system of **ConWIP cards**, which control the amount of work in a work center. ConWIP is an acronym for *constant work-in-process*. The ConWIP card travels with a job (or batch) through the work center. When the job is finished, the card is released and returned to the initial workstation, authorizing the entry of a new

batch into the work center. The ConWIP card effectively limits the amount of work in the work center, controls lead time, and monitors the backlog.

Gantt Charts

Gantt charts are visual aids that are useful in loading and scheduling. The name is derived from Henry Gantt, who developed them in the late 1800s. The charts show the use of resources, such as work centers and labor.

When used in *loading*, Gantt charts show the loading and idle times of several departments, machines, or facilities. They display the relative workloads in the system so that the manager knows what adjustments are appropriate. For example, when one work center becomes overloaded, employees from a low-load center can be transferred temporarily to increase the workforce. Or if waiting jobs can be processed at different work centers, some jobs at high-load centers can be transferred to low-load centers. Versatile equipment may also be transferred among centers. Example 2 illustrates a simple Gantt load chart.

Gantt charts

Planning charts used to schedule resources and allocate time.

Example 2

GANTT LOAD CHART

A New Orleans washing machine manufacturer accepts special orders for machines to be used in such unique facilities as submarines, hospitals, and large industrial laundries. The production of each machine requires varying tasks and durations. The company wants to build a load chart for the week of March 8.

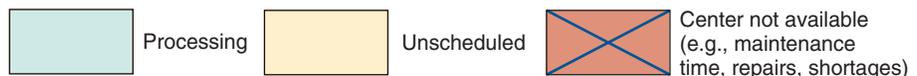
APPROACH ► The Gantt chart is selected as the appropriate graphical tool.

SOLUTION ► Figure 15.3 shows the completed Gantt chart.

Figure 15.3

Gantt Load Chart for the Week of March 8

Work Center \ Day	Monday	Tuesday	Wednesday	Thursday	Friday
Metalworks	Job 349	X	← Job 350 →		
Mechanical		← Job 349 →		Job 408	
Electronics	Job 408			Job 349	
Painting	← Job 295 →		Job 408	X	Job 349



INSIGHT ► The four work centers process several jobs during the week. This particular chart indicates that the metalworks and painting centers are completely loaded for the entire week. The mechanical and electronic centers have some idle time scattered during the week. We also note that the metalworks center is unavailable on Tuesday, and the painting center is unavailable on Thursday, perhaps for preventive maintenance.

LEARNING EXERCISE ► What impact results from the electronics work center closing on Tuesday for preventive maintenance? [Answer: None.]

RELATED PROBLEM ► 15.1b

The Gantt *load chart* has a major limitation: it does not account for production variability such as unexpected breakdowns or human errors that require reworking a job. Consequently, the chart must also be updated regularly to account for new jobs and revised time estimates.

A Gantt *schedule chart* is used to monitor jobs in progress (and is also used for project scheduling). It indicates which jobs are on schedule and which are ahead of or behind schedule. In practice, many versions of the chart are found. The schedule chart in Example 3 places jobs in progress on the vertical axis and time on the horizontal axis.

LO 15.2 Draw Gantt loading and scheduling charts

Example 3

GANTT SCHEDULING CHART

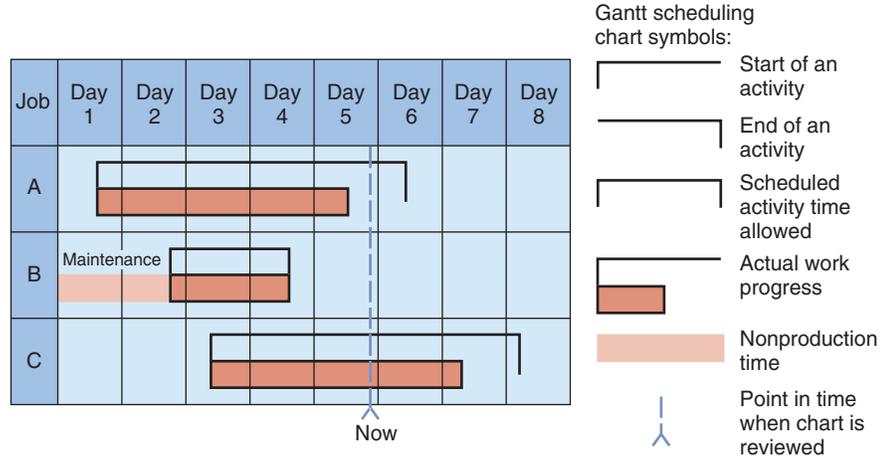
First Printing in Winter Park, Florida, wants to use a Gantt chart to show the scheduling of three orders, jobs A, B, and C.

APPROACH ▶ In Figure 15.4, each pair of brackets on the time axis denotes the estimated starting and finishing of a job enclosed within it. The solid bars reflect the actual status or progress of the job. We are just finishing day 5.

SOLUTION ▶

Figure 15.4

Gantt Scheduling Chart for Jobs A, B, and C at First Printing



INSIGHT ▶ Figure 15.4 illustrates that job A is about a half-day behind schedule at the end of day 5. Job B was completed after equipment maintenance. We also see that job C is ahead of schedule.

LEARNING EXERCISE ▶ Redraw the Gantt chart to show that job A is a half-day *ahead* of schedule. [Answer: The orangish bar now extends all the way to the end of the activity.]

RELATED PROBLEMS ▶ 15.1a, 15.2

Assignment Method

Assignment method

A special class of linear programming models that involves assigning tasks or jobs to resources.

The **assignment method** involves assigning tasks or jobs to resources. Examples include assigning jobs to machines, contracts to bidders, people to projects, and salespeople to territories. The objective is most often to minimize total costs or time required to perform the tasks at hand. One important characteristic of assignment problems is that only one job (or worker) is assigned to one machine (or project).

Each assignment problem uses a table. The numbers in the table will be the costs or times associated with each particular assignment. For example, if First Printing has three available typesetters (A, B, and C) and three new jobs to be completed, its table might appear as follows. The dollar entries represent the firm’s estimate of what it will cost for each job to be completed by each typesetter.

JOB	TYPESETTER		
	A	B	C
R-34	\$11	\$14	\$6
S-66	\$8	\$10	\$11
T-50	\$9	\$12	\$7

The assignment method involves adding and subtracting appropriate numbers in the table to find the lowest *opportunity cost*¹ for each assignment. There are four steps to follow:

1. Subtract the smallest number in each row from every number in that row and then, from the resulting matrix, subtract the smallest number in each column from every number in that column. This step has the effect of reducing the numbers in the table until a series

LO 15.3 Apply the assignment method for loading jobs

- of zeros, meaning *zero opportunity costs*, appear. Even though the numbers change, this reduced problem is equivalent to the original one, and the same solution will be optimal.
2. Draw the minimum number of vertical and horizontal straight lines necessary to cover all zeros in the table. If the number of lines equals either the number of rows or the number of columns in the table, then we can make an optimal assignment (see Step 4). If the number of lines is less than the number of rows or columns, we proceed to Step 3.
 3. Subtract the smallest number not covered by a line from every other uncovered number. Add the same number to any number(s) lying at the intersection of any two lines. Do not change the value of the numbers that are covered by only one line. Return to Step 2 and continue until an optimal assignment is possible.
 4. Optimal assignments will always be at zero locations in the table. One systematic way of making a valid assignment is first to select a row or column that contains only one zero square. We can make an assignment to that square and then draw lines through its row and column. From the uncovered rows and columns, we choose another row or column in which there is only one zero square. We make that assignment and continue the procedure until we have assigned each person or machine to one task.

Example 4 shows how to use the assignment method.

Example 4

ASSIGNMENT METHOD

First Printing wants to find the minimum total cost assignment of 3 jobs to 3 typesetters.

APPROACH ► The cost table shown earlier in this section is repeated here, and steps 1 through 4 are applied.

JOB \ TYPESETTER	A	B	C
R-34	\$11	\$14	\$ 6
S-66	\$ 8	\$10	\$11
T-50	\$ 9	\$12	\$ 7

STUDENT TIP ◆

You can also tackle assignment problems with our Excel OM or POM software or with Excel's Solver add-in.

SOLUTION ►

Step 1A: Using the previous table, subtract the smallest number in each row from every number in the row. The result is shown in the table on the left.

JOB \ TYPESETTER	A	B	C
R-34	5	8	0
S-66	0	2	3
T-50	2	5	0

JOB \ TYPESETTER	A	B	C
R-34	5	6	0
S-66	0	0	3
T-50	2	3	0

Step 1B: Using the above left table, subtract the smallest number in each column from every number in the column. The result is shown in the table on the right.

Step 2: Draw the minimum number of vertical and horizontal straight lines needed to cover all zeros. Because two lines suffice, the solution is not optimal.

JOB \ TYPESETTER	A	B	C
R-34	5	6	0
S-66	0	0	3
T-50	2	3	0

Smallest uncovered number

Step 3: Subtract the smallest uncovered number (2 in this table) from every other uncovered number and add it to numbers at the intersection of two lines.

		TYPESETTER		
		A	B	C
JOB	R-34	3	4	0
	S-66	0	0	5
	T-50	0	1	0

Return to step 2. Cover the zeros with straight lines again.

		TYPESETTER		
		A	B	C
JOB	R-34	3	4	0
	S-66	0	0	5
	T-50	0	1	0

Because three lines are necessary, an optimal assignment can be made (see Step 4). Assign R-34 to person C, S-66 to person B, and T-50 to person A. Referring to the original cost table, we see that:

$$\text{Minimum cost} = \$6 + \$10 + \$9 = \$25$$

INSIGHT ► If we had assigned S-66 to typesetter A, we could not assign T-50 to a zero location.

LEARNING EXERCISE ► If it costs \$10 for Typesetter C to complete Job R-34 (instead of \$6), how does the solution change? [Answer: R-34 to A, S-66 to B, T-50 to C; cost = \$28.]

RELATED PROBLEMS ► 15.3–15.9 (15.11–15.14 are available in [MyOMLab](#))

EXCEL OM Data File [Ch15Ex4.xls](#) can be found in [MyOMLab](#).

Some assignment problems entail *maximizing* profit, effectiveness, or payoff of an assignment of people to tasks or of jobs to machines. An equivalent minimization problem can be obtained by converting every number in the table to an *opportunity loss*. To convert a maximizing problem to an equivalent minimization problem, we create a minimizing table by subtracting every number in the original payoff table from the largest single number in that table. We then proceed to step 1 of the four-step assignment method. Minimizing the opportunity loss produces the same assignment solution as the original maximization problem.

The problem of scheduling major league baseball umpiring crews from one series of games to the next is complicated by many restrictions on travel. The league strives to achieve two conflicting objectives: (1) balance crew assignments relatively evenly among all teams over the course of a season and (2) minimize travel costs. Using the assignment method, the time it takes the league to generate a schedule has been significantly decreased, and the quality of the schedule has improved.



Sequencing Jobs

Once jobs are *loaded* in a work center, as we just discussed, managers decide the *sequence* in which they are to be completed. **Sequencing** (often called *dispatching*) is accomplished by specifying the priority rules to use to release (dispatch) jobs to each work center.

Priority Rules for Sequencing Jobs

Priority rules are especially applicable for process-focused facilities such as clinics, print shops, and manufacturing job shops. The most popular priority rules are:

- ◆ **FCFS: first come, first served.** Jobs are completed in the order they arrived.
- ◆ **SPT: shortest processing time.** Jobs with the shortest processing times are assigned first.
- ◆ **EDD: earliest due date.** Earliest due date jobs are assigned first.
- ◆ **LPT: longest processing time.** Jobs with the longest processing time are assigned first.

Performance Criteria The choice of which priority rule to choose depends in part on how each rule performs on four criteria: the priority rules try to minimize *completion time*, maximize *facility utilization*, minimize *number of jobs in the system*, and minimize *job lateness*. These performance criteria incorporate the concept of **flow time**, which measures the time each job spends waiting plus time being processed. For example, if Job B waits 6 days for Job A to be processed and then takes 2 more days of operation time itself, its flow time would be $6 + 2 = 8$ days. The performance criteria are measured as:

$$\text{Average completion time} = \frac{\text{Sum of total flow time}}{\text{Number of jobs}} \quad (15-1)$$

$$\text{Utilization metric} = \frac{\text{Total job work (processing) time}}{\text{Sum of total flow time}} \quad (15-2)$$

$$\text{Average number of jobs in the system} = \frac{\text{Sum of total flow time}}{\text{Total job work (processing) time}} \quad (15-3)$$

$$\text{Average job lateness} = \frac{\text{Total late days}}{\text{Number of jobs}} \quad (15-4)$$

Computing the lateness of a particular job involves assumptions about the start time during the day and the timing of delivering a completed job. Equation (15-5) assumes that today is a work day, work has not yet begun today, and a job finished by the end of a day can be delivered to the customer that same day.

$$\text{Job lateness} = \text{Max}\{0, \text{yesterday} + \text{flow time} - \text{due date}\} \quad (15-5)$$

For example, suppose that today is day 20 (thus yesterday was day 19). Job A is due tomorrow (day 21) and has a flow time of 1 day. That job would be considered to be completed on time, i.e., not late:

$$\text{Max}\{0, 19 + 1 - 21\} = \text{Max}\{0, -1\} = 0 \text{ days late.}$$

Meanwhile, Job B is due on day 32 and has a flow time of 15 days. The lateness of Job B would be:

$$\text{Max}\{0, 19 + 15 - 32\} = \text{Max}\{0, 2\} = 2 \text{ days late.}$$

We will examine four of the most popular priority rules in Example 5.

Sequencing

Determining the order in which jobs should be done at each work center.

Priority rules

Rules used to determine the sequence of jobs in process-oriented facilities.

Flow time

The time between the release of a job to a work center until the job is finished.

Example 5

PRIORITY RULES FOR DISPATCHING

Five architectural rendering jobs are waiting to be assigned at Avanti Sethi Architects. Their work (processing) times and due dates are given in the following table. The firm wants to determine the sequence of processing according to (1) FCFS, (2) SPT, (3) EDD, and (4) LPT rules. Jobs were assigned a letter in the order they arrived. Today is day 1, and work begins today.

JOB	JOB WORK (PROCESSING) TIME (DAYS)	JOB DUE DATE (DAYS)
A	6	8
B	2	6
C	8	18
D	3	15
E	9	23

APPROACH ► Each of the four priority rules is examined in turn. Four measures of effectiveness can be computed for each rule and then compared to see which rule is best for the company.

SOLUTION ►

1. The *FCFS* sequence shown in the next table is simply A–B–C–D–E.

JOB SEQUENCE	JOB WORK (PROCESSING) TIME	FLOW TIME	JOB DUE DATE	JOB LATENESS
A	6	6	8	0
B	2	8	6	2
C	8	16	18	0
D	3	19	15	4
E	9	28	23	5
	28	77		11

The *FCFS* rule results in the following measures of effectiveness:

$$\begin{aligned} \text{a. Average completion time} &= \frac{\text{Sum of total flow time}}{\text{Number of jobs}} \\ &= \frac{77 \text{ days}}{5} = 15.4 \text{ days} \end{aligned}$$

$$\begin{aligned} \text{b. Utilization metric} &= \frac{\text{Total job work (processing) time}}{\text{Sum of total flow time}} \\ &= \frac{28}{77} = 36.4\% \end{aligned}$$

$$\begin{aligned} \text{c. Average number of jobs in the system} &= \frac{\text{Sum of total flow time}}{\text{Total job work (processing) time}} \\ &= \frac{77 \text{ days}}{28 \text{ days}} = 2.75 \text{ jobs} \end{aligned}$$

$$\text{d. Average job lateness} = \frac{\text{Total late days}}{\text{Number of jobs}} = \frac{11}{5} = 2.2 \text{ days}$$

2. The *SPT* rule shown in the next table results in the sequence B–D–A–C–E. Orders are sequenced according to processing time, with the highest priority given to the shortest job.

JOB SEQUENCE	JOB WORK (PROCESSING) TIME	FLOW TIME	JOB DUE DATE	JOB LATENESS
B	2	2	6	0
D	3	5	15	0
A	6	11	8	3
C	8	19	18	1
E	9	28	23	5
	28	65		9

Measurements of effectiveness for *SPT* are:

$$\text{a. Average completion time} = \frac{65}{5} = 13 \text{ days}$$

$$\text{b. Utilization metric} = \frac{28}{65} = 43.1\%$$

$$\text{c. Average number of jobs in the system} = \frac{65}{28} = 2.32 \text{ jobs}$$

$$\text{d. Average job lateness} = \frac{9}{5} = 1.8 \text{ days}$$

LO 15.4 Name and describe each of the priority sequencing rules

3. The *EDD* rule shown in the next table gives the sequence B–A–D–C–E. Note that jobs are ordered by earliest due date first.

JOB SEQUENCE	JOB WORK (PROCESSING) TIME	FLOW TIME	JOB DUE DATE	JOB LATENESS
B	2	2	6	0
A	6	8	8	0
D	3	11	15	0
C	8	19	18	1
E	9	28	23	5
	28	68		6

Measurements of effectiveness for EDD are:

- a. Average completion time = $\frac{68}{5} = 13.6$ days
 - b. Utilization metric = $\frac{28}{68} = 41.2\%$
 - c. Average number of jobs in the system = $\frac{68}{28} = 2.43$ jobs
 - d. Average job lateness = $\frac{6}{5} = 1.2$ days
4. The *LPT* rule shown in the next table results in the order E–C–A–D–B.

JOB SEQUENCE	JOB WORK (PROCESSING) TIME	FLOW TIME	JOB DUE DATE	JOB LATENESS
E	9	9	23	0
C	8	17	18	0
A	6	23	8	15
D	3	26	15	11
B	2	28	6	22
	28	103		48

Measures of effectiveness for LPT are:

- a. Average completion time = $\frac{103}{5} = 20.6$ days
- b. Utilization metric = $\frac{28}{103} = 27.2\%$
- c. Average number of jobs in the system = $\frac{103}{28} = 3.68$ jobs
- d. Average job lateness = $\frac{48}{5} = 9.6$ days

The results of these four rules are summarized in the following table:

RULE	AVERAGE COMPLETION TIME (DAYS)	UTILIZATION METRIC (%)	AVERAGE NUMBER OF JOBS IN SYSTEM	AVERAGE LATENESS (DAYS)
FCFS	15.4	36.4	2.75	2.2
SPT	13.0	43.1	2.32	1.8
EDD	13.6	41.2	2.43	1.2
LPT	20.6	27.2	3.68	9.6

INSIGHT ▶ LPT is the least effective measurement for sequencing for the Avanti Sethi firm. SPT is superior in 3 measures, and EDD is superior in the fourth (average lateness).

LEARNING EXERCISE ▶ If job A takes 7 days (instead of 6), how do the 4 measures of effectiveness change under the FCFS rule? [Answer: 16.4 days, 35.4%, 2.83 jobs, 2.8 days late.]

RELATED PROBLEMS ▶ 15.15, 15.17a–d, 15.18, 15.19 (15.15 alternate, 15.24 are available in MyOMLab)

EXCEL OM Data File Ch15Ex5.xls can be found in MyOMLab.

ACTIVE MODEL 15.1 This example is further illustrated in Active Model 15.1 in MyOMLab.

Your doctor may use a first-come, first-served priority rule satisfactorily. However, such a rule may be less than optimal for this emergency room. What priority rule might be best, and why? What priority rule is often used on TV hospital dramas?



Tyler Olson/Fotolia

The results in Example 5 are typically true in the real world also. No one sequencing rule always excels on all criteria. Experience indicates the following:

1. **Shortest processing time** is generally the best technique for minimizing job flow and minimizing the average number of jobs in the system. Its chief disadvantage is that long-duration jobs may be continuously pushed back in priority in favor of short-duration jobs. Customers may view this dimly, and a periodic adjustment for longer jobs must be made.
2. **First come, first served** does not score well on most criteria (but neither does it score particularly poorly). It has the advantage, however, of appearing fair to customers, which is important in service systems.
3. **Earliest due date** minimizes maximum tardiness, which may be necessary for jobs that have a very heavy penalty after a certain date. In general, EDD works well when lateness is an issue.

Critical Ratio

For organizations that have due dates (such as manufacturers and many firms like your local printer and furniture re-upholsterer), the critical ratio for sequencing jobs is beneficial. The **critical ratio (CR)** is an index number computed by dividing the time remaining until due date by the work time remaining. As opposed to the priority rules, critical ratio is dynamic and easily updated. It tends to perform better than FCFS, SPT, EDD, or LPT on the average job-lateness criterion.

The critical ratio gives priority to jobs that must be done to keep shipping on schedule. A job with a low critical ratio (less than 1.0) is one that is falling behind schedule. If CR is exactly 1.0, the job is on schedule. A CR greater than 1.0 means the job is ahead of schedule and has some slack.

The formula for critical ratio is:

$$CR = \frac{\text{Time remaining}}{\text{Workdays remaining}} = \frac{\text{Due date} - \text{Today's date}}{\text{Work (lead) time remaining}} \quad (15-6)$$

Example 6 shows how to use the critical ratio.

Critical ratio (CR)

A sequencing rule that is an index number computed by dividing the time remaining until due date by the work time remaining.

Example 6

CRITICAL RATIO

Today is day 25 on Zyc Medical Testing Laboratories' production schedule. Three jobs are on order, as indicated here:

JOB	DUE DATE	WORKDAYS REMAINING
A	30	4
B	28	5
C	27	2

APPROACH ► Zyco wants to compute the critical ratios, using the formula for CR.

SOLUTION ►

JOB	CRITICAL RATIO	PRIORITY ORDER
A	$(30 - 25)/4 = 1.25$	3
B	$(28 - 25)/5 = .60$	1
C	$(27 - 25)/2 = 1.00$	2

INSIGHT ► Job B has a critical ratio of less than 1, meaning it will be late unless expedited. Thus, it has the highest priority. Job C is on time, and job A has some slack. Once job B has been completed, we would recompute the critical ratios for jobs A and C to determine whether their priorities have changed.

LEARNING EXERCISE ► Today is day 24 (a day earlier) on Zyco’s schedule. Recompute the CRs and determine the priorities. [Answer: 1.5, 0.8, 1.5; B is still number 1, but now jobs A and C are tied for second.]

RELATED PROBLEMS ► 15.16, 15.17e, 15.21

In most production scheduling systems, the critical-ratio rule can help do the following:

1. Determine the status of a specific job.
2. Establish relative priority among jobs on a common basis.
3. Adjust priorities (and revise schedules) automatically for changes in both demand and job progress.
4. Dynamically track job progress.

Sequencing *N* Jobs on Two Machines: Johnson’s Rule

The next step in complexity is the case in which *N* jobs (where *N* is 2 or more) must go through two different machines or work centers in the same order. (Each work center only works on one job at a time.) This is called the *N*/2 problem.

Johnson’s rule can be used to minimize the time for sequencing a group of jobs through two work centers. It also minimizes total idle time on the machines. *Johnson’s rule* involves four steps:

1. All jobs are to be listed, and the time that each requires on a machine is to be shown.
2. Select the job with the shortest activity time. If the shortest time lies with the first machine, the job is scheduled first. If the shortest time lies with the second machine, schedule the job last. Ties in activity times can be broken arbitrarily.
3. Once a job is scheduled, eliminate it.
4. Apply steps 2 and 3 to the remaining jobs, working toward the center of the sequence.

Johnson’s rule

An approach that minimizes the total time for sequencing a group of jobs through two work centers while minimizing total idle time in the work centers.

Example 7 shows how to apply Johnson’s rule.

Example 7

JOHNSON’S RULE

Five specialty jobs at a La Crosse, Wisconsin, tool and die shop must be processed through two work centers (drill press and lathe). The time for processing each job follows:

Work (processing) Time for Jobs (hours)

JOB	WORK CENTER 1 (DRILL PRESS)	WORK CENTER 2 (LATHE)
A	5	2
B	3	6
C	8	4
D	10	7
E	7	12

The owner, Niranjan Pati, wants to set the sequence to minimize his total time for the five jobs.

LO 15.5 Use Johnson's rule

APPROACH ▶ Pati applies the four steps of Johnson's rule.

SOLUTION ▶

1. The job with the shortest processing time is A, in work center 2 (with a time of 2 hours). Because it is at the second center, schedule A last. Eliminate it from consideration.



2. Job B has the next shortest time (3 hours). Because that time is at the first work center, we schedule it first and eliminate it from consideration.



3. The next shortest time is job C (4 hours) on the second machine. Therefore, it is placed as late as possible.



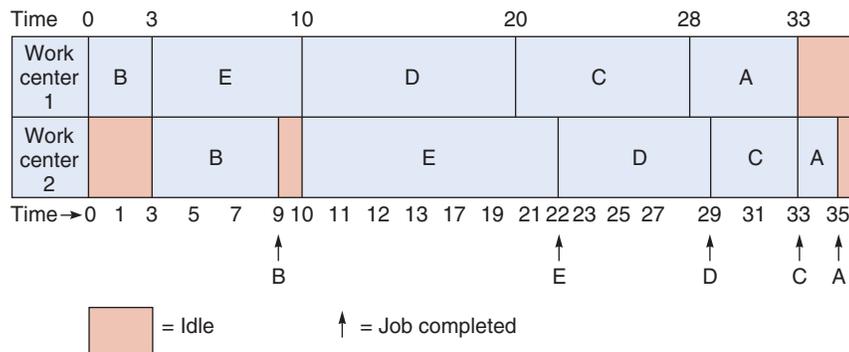
4. There is a tie (at 7 hours) for the shortest remaining job. We can place E, which was on the first work center, first. Then D is placed in the last sequencing position:



The sequential times are:

Work center 1	3	7	10	8	5
Work center 2	6	12	7	4	2

The time-phased flow of this job sequence is best illustrated graphically:



Thus, the five jobs are completed in 35 hours.

INSIGHT ▶ The second work center will wait 3 hours for its first job, and it will also wait 1 hour after completing job B.

LEARNING EXERCISE ▶ If job C takes 8 hours in work center 2 (instead of 4 hours), what sequence is best? [Answer: B–E–C–D–A.]

RELATED PROBLEMS ▶ 15.20, 15.22, 15.23 (15.25 is available in MyOMLab)

EXCEL OM Data File Ch15Ex7.xls can be found in MyOMLab.

Limitations of Rule-Based Sequencing Systems

The scheduling techniques just discussed are rule-based techniques, but rule-based systems have a number of limitations. Among these are the following:

1. Scheduling is dynamic; therefore, rules need to be revised to adjust to changes in orders, process, equipment, product mix, and so forth.

- Rules do not look upstream or downstream; idle resources and bottleneck resources in other departments may not be recognized.
- Rules do not look beyond due dates. For instance, two orders may have the same due date. One order involves restocking a distributor and the other is a custom order that will shut down the customer's factory if not completed. Both may have the same due date, but clearly the custom order is more important.

Despite these limitations, schedulers often use sequencing rules such as SPT, EDD, or critical ratio. They apply these methods at each work center and then modify the sequence to deal with a multitude of real-world variables. They may do this manually or with finite capacity scheduling software.

Finite Capacity Scheduling (FCS)

Short-term scheduling systems are also called finite capacity scheduling.² **Finite capacity scheduling (FCS)** overcomes the disadvantages of systems based exclusively on rules by providing the scheduler with interactive computing and graphic output. In dynamic scheduling environments such as job shops (with high variety, low volume, and shared resources) we expect changes. But changes disrupt schedules. Operations managers are moving toward FCS systems that allow virtually instantaneous change by the operator. Improvements in communication on the shop floor are also enhancing the accuracy and speed of information necessary for effective control in job shops. Computer-controlled machines can monitor events and collect information in near real-time. This means the scheduler can make schedule changes based on up-to-the-minute information. These schedules are often displayed in Gantt chart form. In addition to including priority rule options, many of the current FCS systems also combine an “expert system” or simulation techniques and allow the scheduler to assign costs to various options. The scheduler has the flexibility to handle any situation, including order, labor, or machine changes.

The combining of planning and FCS data, priority rules, models to assist analysis, and Gantt chart output is shown in Figure 15.5.

Finite capacity scheduling allows delivery requirements to be based on today's conditions and today's orders, not according to some predefined rule. The scheduler determines what constitutes a “good” schedule. FCS software packages such as Lekin (shown in Figure 15.6), ProPlanner, Preactor, Asprova, Schedlyzer, and Jobplan are currently used at over 60% of U.S. plants.

Finite capacity scheduling (FCS)

Computerized short-term scheduling that overcomes the disadvantage of rule-based systems by providing the user with graphical interactive computing.

LO 15.6 Define finite capacity scheduling

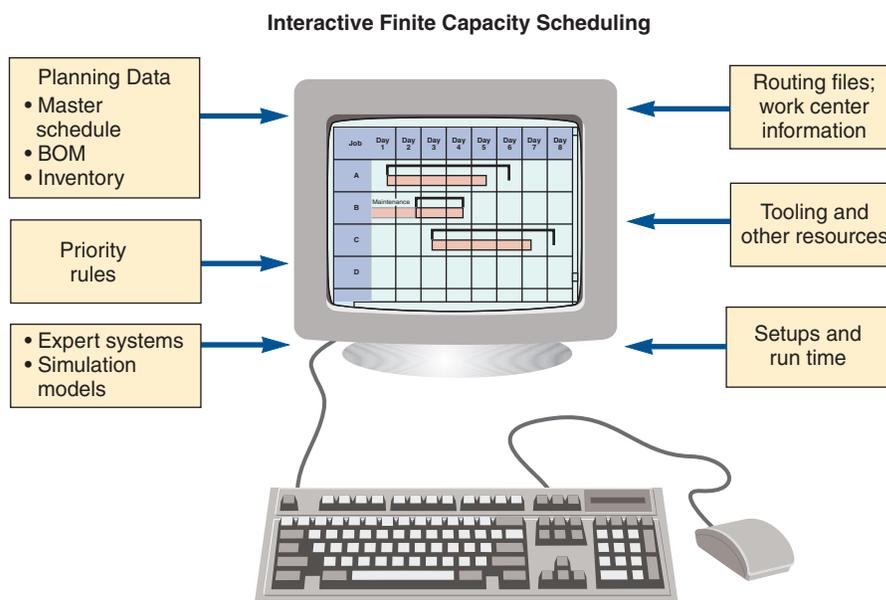


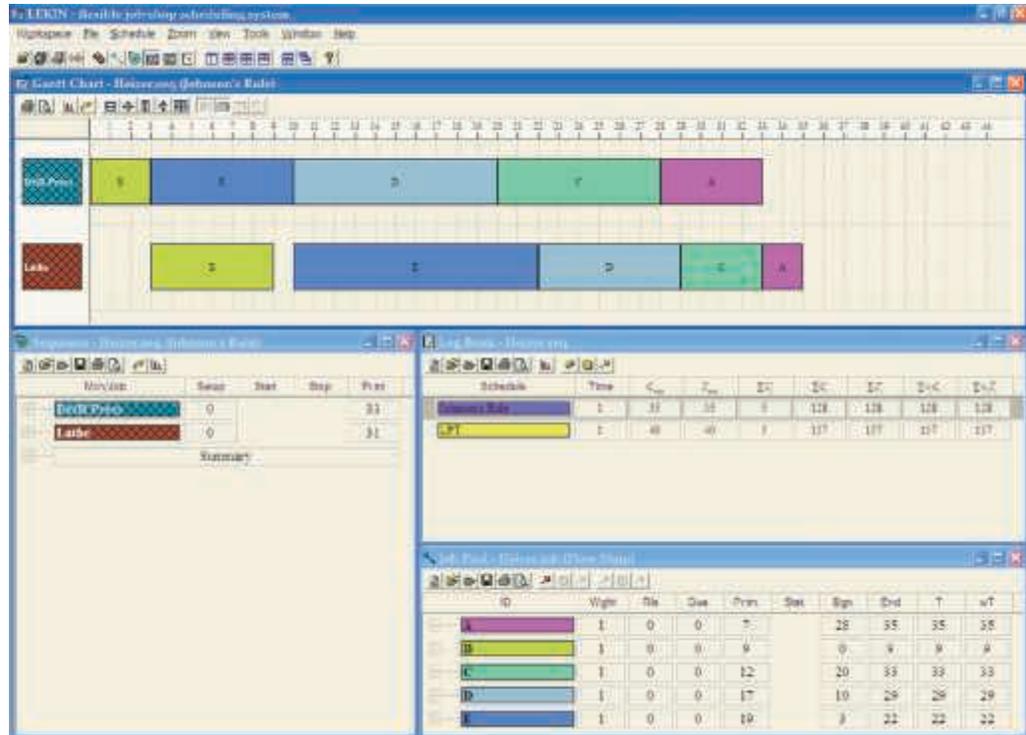
Figure 15.5

Finite Capacity Scheduling Systems Use Production Data to Generate Gantt Load Charts, and Work-in-Process Data That Can Be Manipulated by the User to Evaluate Schedule Alternatives

Figure 15.6

Finite Capacity Scheduling (FCS) System

This Lekin® finite capacity scheduling software presents a schedule of the five jobs and the two work centers shown in Example 7 (pages 615–616) in Gantt chart form. The software is capable of using a variety of priority rules and many jobs. The Lekin software is available for free at <http://community.stern.nyu.edu/om/software/lekin/download.html> and can solve many of the problems at the end of this chapter.



Screenshot from Lekin® Finite Capacity Scheduling Software. Reprinted with permission.

Scheduling Services

STUDENT TIP ⚡ Scheduling service systems differs from scheduling manufacturing systems in several ways:

Scheduling people to perform services can be even more complex than scheduling machines.

- ◆ In manufacturing, the scheduling emphasis is on machines and materials; in services, it is on staffing levels.
- ◆ Inventories can help smooth demand for manufacturers, but many service systems do not maintain inventories.
- ◆ Services are labor intensive, and the demand for this labor can be highly variable.
- ◆ Legal considerations, such as wage and hour laws and union contracts that limit hours worked per shift, week, or month, constrain scheduling decisions.
- ◆ Because services usually schedule people (rather than material), social, fatigue, seniority, and status issues complicate scheduling.

The following examples note the complexity of scheduling services.

VIDEO 15.2

Scheduling at Hard Rock Cafe

Hospitals A hospital is an example of a service facility that may use a scheduling system every bit as complex as one found in a job shop. Hospitals seldom use a machine shop priority system such as first come, first served (FCFS) for treating emergency patients, but they often use FCFS *within* a priority class, a “triage” approach. And they often schedule products (such as surgeries) just like a factory, maintaining excess capacity to meet wide variations in demand.

Banks Cross-training of the workforce in a bank allows loan officers and other managers to provide short-term help for tellers if there is a surge in demand. Banks also employ part-time personnel to provide a variable capacity.

Retail Stores Scheduling optimization systems, such as Workbrain, Cybershift, and Kronos, are used at retailers including Walmart, Payless Shoes, and Target. These systems track individual store sales, transactions, units sold, and customer traffic in 15-minute increments to create work schedules. Walmart’s 2.2 million and Target’s 350,000 employees used to take thousands of managers’ hours to schedule; now staffing is drawn up nationwide in a few hours, and customer checkout experience has improved dramatically.

Starbucks’ scheduling software is discussed in the *OM in Action* box on the next page.

OM in Action

Starbucks' Controversial Scheduling Software

Starbucks recently announced revisions to the way the company schedules its 130,000 baristas, saying it wanted to improve “stability and consistency” in work hours from week to week. The company intends to curb the much-loathed practice of “clopening,” or workers closing the store late at night and returning just a few hours later to reopen. All work hours must be posted at least one week in advance, a policy that has been only loosely followed in the past. Baristas with more than an hour’s commute will be given the option to transfer to more convenient locations, and scheduling software will be revised to allow more input from managers.

The revisions came in response to a newspaper article about a single mother struggling to keep up with erratic hours set by automated software. A growing push to curb scheduling practices, enabled by sophisticated software, has caused havoc in employees’ lives: giving only a few days’ notice of working hours; sending workers home early when sales are slow; and shifting hours significantly from week to week. Those practices have been common at Starbucks. And many other chains use even more severe methods, such as requiring workers to have “open availability,” or be able to work anytime they are needed, or to stay “on call,” meaning they only find out that morning if they are needed.

Starbucks prides itself on progressive labor practices, such as offering health benefits, free online degrees at Arizona State University, and stock. But baristas across the country say that their actual working conditions vary



RosalreneBetancourt / Alamy

wildly, and that the company often fails to live up to its professed ideals, by refusing to offer any guaranteed hours to part-time workers and keeping many workers’ pay at minimum wage. Scheduling has been an issue for years. Said a former company executive: “Labor is the biggest controllable cost for front-line operators, who are under incredible pressure to hit financial targets.”

Sources: *New York Times* (September 24, 2015 and August 15, 2014) and *BloombergBusinessweek* (August 15, 2014).

Airlines Two of the constraints airlines face when scheduling flight crews are: (1) a complex set of FAA work-time limitations and (2) union contracts that guarantee crew pay for some number of hours each day or each trip. Planners must also make efficient use of their other expensive resource: aircraft. These schedules are typically built using linear programming models.

24/7 Operations Emergency hotlines, police/fire departments, telephone operations, and mail-order businesses (such as L.L.Bean) schedule employees 24 hours a day, 7 days a week. To allow management flexibility in staffing, sometimes part-time workers can be employed. This provides both benefits (in using odd shift lengths or matching anticipated workloads) and difficulties (from the large number of possible alternatives in terms of days off, lunch hour times, rest periods, starting times). Most companies use computerized scheduling systems to cope with these complexities.



Patricia McDomnell/AP Images

Good scheduling in the health care industry can help keep nurses happy and costs contained. Here, nurses in Boston protest nurse-staffing levels in Massachusetts hospitals. Shortages of qualified nurses is a chronic problem.

Scheduling Service Employees with Cyclical Scheduling

A number of techniques and algorithms exist for scheduling service-sector employees when staffing needs vary. This is typically the case for police officers, nurses, restaurant staff, tellers, and retail sales clerks. Managers, trying to set a timely and efficient schedule that keeps personnel happy, can spend substantial time each month developing employee schedules. Such schedules often consider a fairly long planning period (say, 6 weeks). One approach that is workable yet simple is *cyclical scheduling*.

LO 15.7 Use the cyclical scheduling technique

Cyclical Scheduling Cyclical scheduling focuses on developing varying (inconsistent) schedules with the minimum number of workers. In these cases, each employee is assigned to a shift and has prescribed time off. Let’s look at Example 8.

Example 8

CYCLICAL SCHEDULING

Hospital administrator Doris Laughlin wants to staff the oncology ward using a standard 5-day work-week with two consecutive days off, but also wants to minimize the staff. However, as in most hospitals, she faces an inconsistent demand. Weekends have low usage. Doctors tend to work early in the week, and patients peak on Wednesday then taper off.

APPROACH ► Doris must first establish staffing requirements. Then the following five-step process is applied.

SOLUTION ►

1. Doris has determined that the necessary daily staffing requirements are:

DAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY	SUNDAY
Staff required	5	5	6	5	4	3	3

2. Identify the two consecutive days that have the *lowest total requirement* and circle these. Assign these two days off to the first employee. In this case, the first employee has Saturday and Sunday off because 3 plus 3 is the *lowest sum* of any 2 days. In the case of a tie, choose the days with the lowest adjacent requirement, or by first assigning Saturday and Sunday as an “off” day. If there are more than one, make an arbitrary decision.
3. We now have an employee working each of the uncircled days; therefore, make a new row for the next employee by subtracting 1 from the first row (because one day has been worked)—except for the circled days (which represent the days not worked) and any day that has a zero. That is, do not subtract from a circled day or a day that has a value of zero.
4. In the new row, identify the two consecutive days that have the lowest total requirement and circle them. Assign the next employee to the remaining days.
5. Repeat the process (Steps 3 and 4) until all staffing requirements are met.

	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY	SUNDAY
Employee 1	5	5	6	5	4	3	3
Employee 2	4	4	5	4	3	3	3
Employee 3	3	3	4	3	2	3	3
Employee 4	2	2	3	2	2	3	2
Employee 5	1	1	2	2	2	2	1
Employee 6	1	1	1	1	1	1	0
Employee 7						1	

Capacity (measured in number of employees)	5	5	6	5	4	3	3
Excess capacity	0	0	0	0	0	1	0

Doris needs six full-time employees to meet the staffing needs and one employee to work Saturday.

Notice that capacity (number of employees) equals requirements, provided an employee works overtime on Saturday, or a part-time employee is hired for Saturday.

INSIGHT ► Doris has implemented an efficient scheduling system that accommodates 2 consecutive days off for every employee.

LEARNING EXERCISE ► If Doris meets the staffing requirement for Saturday with a full-time employee, how does she schedule that employee? [Answer: That employee can have any 2 days off, except Saturday, and capacity will exceed requirements by 1 person each day the employee works (except Saturday).]

RELATED PROBLEMS ► 15.26, 15.27

Using the approach in Example 8, Colorado General Hospital saved an average of 10 to 15 hours a month and found these added advantages: (1) no computer was needed, (2) the nurses were happy with the schedule, (3) the cycles could be changed seasonally to accommodate avid skiers, and (4) recruiting was easier because of predictability and flexibility. This approach yields an optimum, although there may be multiple optimal solutions.

Other cyclical scheduling techniques have been developed to aid service scheduling. Some approaches use linear programming: This is how Hard Rock Cafe schedules its services (see the Video Case Study at the end of this chapter). There is a natural bias in scheduling to use tools that are understood and yield solutions that are accepted.

Summary

Scheduling involves the timing of operations to achieve the efficient movement of units through a system. This chapter addressed the issues of short-term scheduling in process-focused and service environments. We saw that process-focused facilities are production systems in which products are made to order and that scheduling tasks in them can become complex. Several aspects and approaches to scheduling, loading, and sequencing of jobs were introduced. These

ranged from Gantt charts and the assignment method of scheduling to a series of priority rules, the critical-ratio rule, Johnson's rule for sequencing, and finite capacity scheduling.

Service systems generally differ from manufacturing systems. This leads to the use of first-come, first-served rules and appointment and reservation systems, as well as linear programming for matching capacity to demand in service environments.

Key Terms

Loading (p. 604)
Input-output control (p. 606)
ConWIP cards (p. 606)
Gantt charts (p. 607)

Assignment method (p. 608)
Sequencing (p. 611)
Priority rules (p. 611)
Flow time (p. 611)

Critical ratio (CR) (p. 614)
Johnson's rule (p. 615)
Finite capacity scheduling
(FCS) (p. 617)

Ethical Dilemma

Scheduling people to work second and third shifts (evening and "graveyard") is a problem in almost every 24-hour company. Medical and ergonomic data indicate the body does not respond well to significant shifts in its natural circadian rhythm of sleep.

There are also significant long-run health issues with frequent changes in work and sleep cycles.

Consider yourself the manager of a nonunion steel mill that must operate 24-hour days, and where the physical demands are such that 8-hour days are preferable to 10- or 12-hour days.

Your empowered employees have decided that they want to work weekly rotating shifts. That is, they want a repeating work cycle of 1 week, 7 A.M. to 3 P.M., followed by a second week from 3 P.M. to 11 P.M., and the third week from 11 P.M. to 7 P.M. You are sure this is not a good idea in terms of both productivity and the long-term health of the employees. If you do not accept their decision, you undermine the work empowerment program, generate a morale issue, and perhaps, more significantly, generate few more votes for a union. What is the ethical position and what do you do?



Marcel Moolij/Shutterstock

Discussion Questions

1. What is the overall objective of scheduling?
2. List the four criteria for determining the effectiveness of a *scheduling* decision. How do these criteria relate to the four criteria for *sequencing* decisions?
3. Describe what is meant by “loading” work centers. What are the two ways work centers can be loaded? What are two techniques used in loading?
4. Name five priority sequencing rules. Explain how each works to assign jobs.
5. What are the advantages and disadvantages of the shortest processing time (SPT) rule?
6. What is a due date?
7. Explain the terms *flow time* and *lateness*.
8. Which shop-floor scheduling rule would you prefer to apply if you were the leader of the only team of experts charged with defusing several time bombs scattered throughout your building? You can see the bombs; they are of different types. You can tell how long each one will take to defuse. Discuss.
9. When is Johnson’s rule best applied in job-shop scheduling?
10. State the four effectiveness measures for dispatching rules.
11. What are the steps of the assignment method of linear programming?
12. What are the advantages to finite capacity scheduling?
13. What is input–output control?

Using Software for Short-Term Scheduling

In addition to the commercial software we noted in this chapter, short-term scheduling problems can be solved with the Excel OM software that comes free with this text. POM for Windows also includes a scheduling module. The use of each of these programs is explained next.

✕ USING EXCEL OM

Excel OM has two modules that help solve short-term scheduling problems: Assignment and Job Shop Scheduling. The Assignment module is illustrated in Programs 15.1 and 15.2. The input screen, using the Example 4 data, appears first, as Program 15.1. Once the data are all entered, we choose the **Data tab** command, followed by the **Solver** command. Excel’s Solver uses linear programming to optimize assignment problems. (So select Simplex LP.)

The constraints are also shown in Program 15.1. We then select the **Solve** command; the solution appears in Program 15.2.

Excel OM’s Job Shop Scheduling module is illustrated in Program 15.3. Program 15.3 uses Example 5’s data. Because jobs are listed in the sequence in which they arrived (see column A), the results are for the FCFS rule. Program 15.3 also shows some of the formulas (columns F, G, H, I, J) used in the calculations.

To solve with the SPT rule, we need four intermediate steps: (1) Select (that is, highlight) the data in columns A, B, C for all jobs; (2) invoke the **Data** command; (3) invoke the **Sort** command; and (4) sort by **Time** (column C) in *ascending* order. To solve for EDD, Step 4 changes to sort by **Due Date** (column D) in *ascending* order. Finally, for an LPT solution, Step 4 becomes sort by **Due Date** (column D) in *descending* order.

In Excel 2007 and later for PCs and Excel 2016 for Macs, Solver is in the Analysis section of the Data tab. In Excel 2011 for Macs, Solver is under the Tools menu.

Solver Parameters

- Set Objective: $\$B\2 (B22 is where we placed our total costs on the data screen.)
- To: \leq \geq $=$ $<$ $>$ $<=$ $>=$ $<=>$
- By Changing Variable Cells: $\$B\$10:\$D\10 (These are the cells that we will ask Excel's Solver to fill in for us.)
- Subject to the Constraints: $\$D\$10:\$D\$10 = 1$, $\$E\$10:\$E\$10 = 1$ (These are the constraints for the linear programming representation of the assignment problem.)
- Make Unconstrained Variables Non-Negative (We need to create row and column totals in order to create the constraints. Nonnegativity constraints have been added through the checkbox.)
- Select a Solving Method: Simplex LP (Select Simplex LP as the solution method.)

Spreadsheet Data:

Costs	A	B	C
R-34	11	14	6
S-86	8	10	11
T-50	9	12	7

Shipments	A	B	C	Row Total
R-34				=SUM(B10:D10)
S-86				=SUM(B11:D11)
T-50				=SUM(B12:D12)
Column Total	=SUM(B10:B12)	=SUM(C10:C12)	=SUM(D10:D12)	=SUM(E10:E12)

Total Cost: $=SUMPRODUCT(B10:D12,E10:E12)$

Copy the names from the above table.

The assignments will be filled in by Excel's Solver.

Use the SUMPRODUCT function to calculate the total cost. Notice that this function is multiplying the data table by the assignment table.

Program 15.1

Excel OM's Assignment Module Using Example 4's Data

After entering the problem data in the yellow area, select Data, then Solver.

Solver Results

Solver found a solution. All Constraints and optimality conditions are satisfied.

- Keep Solver Solution
- Restore Original Values
- Return to Solver Parameters Dialog
- Outline Reports

Reports: Answer, Sensitivity, Limits

Solver found a solution. All Constraints and optimality conditions are satisfied.

When the GRG engine is used, Solver has found at least a local optimal solution. When Simplex LP is used, this means Solver has found a global optimal solution.

It is important to check the statement made by the Solver. In this case, it says that Solver found a solution. In other problems, this may not be the case. For some problems there may be no feasible solution, and for others more iterations may be required.

Spreadsheet Data:

Shipments	A	B	C	Row Total
R-34				1
S-86			1	1
T-50	1			1
Column Total	1	1	1	3

Total Cost: 25

Solver has filled in the assignments with 1s.

Program 15.2

Excel OM Output Screen for Assignment Problem Described in Program 15.1

In this example, all work begins on Day 1 and all jobs are available on Day 1.

The results are for an FCFS schedule. To create other results, sort cells A9 through D13 based on a new criterion.

Calculate the slack as = D9 - C9.

An IF function is used to determine whether or not the job was late. = IF(I13-D13>=0, I13-D13,0)

The completion times and the flow times are identical since work begins on Day 1

= H14/C14 = AVERAGE(H9:H13)

Program 15.3

Excel OM's Job Shop Scheduling Module Applied to Example 5's Data

USING POM FOR WINDOWS

POM for Windows can handle both categories of scheduling problems we see in this chapter. Its Assignment module is used to solve the traditional one-to-one assignment problem of people to tasks, machines to jobs, and so on. Its Job Shop Scheduling module can solve a one- or two-machine job-shop problem. Available priority rules include SPT, FCFS, EDD, and LPT. Each can be examined in turn once the data are all entered. Refer to Appendix IV for specifics regarding POM for Windows.

Solved Problems

Virtual Office Hours help is available in MyOMLab.

SOLVED PROBLEM 15.1

King Finance Corporation, headquartered in New York, wants to assign three recently hired college graduates, Julie Jones, Al Smith, and Pat Wilson, to regional offices. However, the firm also has an opening in New York and would send one of the three there if it were more economical than a move to Omaha, Dallas, or Miami. It will cost \$1,000 to relocate Jones to New York, \$800 to relocate Smith there, and \$1,500 to move Wilson. What is the optimal assignment of personnel to offices?

	OFFICE	OMAHA	MIAMI	DALLAS
HIREE				
Jones		\$800	\$1,100	\$1,200
Smith		\$500	\$1,600	\$1,300
Wilson		\$500	\$1,000	\$2,300

SOLUTION

a) The cost table has a fourth column to represent New York. To "balance" the problem, we add a "dummy" row (person) with a zero relocation cost to each city.

b) Subtract the smallest number in each row and cover all zeros (column subtraction of each column's zero will give the same numbers and therefore is not necessary):

	OFFICE	OMAHA	MIAMI	DALLAS	NEW YORK
HIREE					
Jones		\$800	\$1,100	\$1,200	\$1,000
Smith		\$500	\$1,600	\$1,300	\$ 800
Wilson		\$500	\$1,000	\$2,300	\$1,500
Dummy		0	0	0	0

	OFFICE	OMAHA	MIAMI	DALLAS	NEW YORK
HIREE					
Jones		0	300	400	200
Smith		0	1,100	800	300
Wilson		0	500	1,800	1,000
Dummy		0	0	0	0

c) Only 2 lines cover, so subtract the smallest uncovered number (200) from all uncovered numbers, and add it to each square where two lines intersect. Then cover all zeros:

OFFICE \ HIREE	OMAHA	MIAMI	DALLAS	NEW YORK
Jones	0	100	200	0
Smith	0	900	600	100
Wilson	0	300	1,600	800
Dummy	200	0	0	0

d) Only 3 lines cover, so subtract the smallest uncovered number (100) from all uncovered numbers, and add it to each square where two lines intersect. Then cover all zeros:

OFFICE \ HIREE	OMAHA	MIAMI	DALLAS	NEW YORK
Jones	0	0	100	0
Smith	0	800	500	100
Wilson	0	200	1,500	800
Dummy	300	0	0	100

e) Still only 3 lines cover, so subtract the smallest uncovered number (100) from all uncovered numbers, add it to squares where two lines intersect, and cover all zeros:

OFFICE \ HIREE	OMAHA	MIAMI	DALLAS	NEW YORK
Jones	100	0	100	0
Smith	0	700	400	0
Wilson	0	100	1,400	700
Dummy	400	0	0	100

f) Because it takes four lines to cover all zeros, an optimal assignment can be made at zero squares. We assign:

- Wilson to Omaha
- Jones to Miami
- Dummy (no one) to Dallas
- Smith to New York

$$\begin{aligned} \text{Cost} &= \$500 + \$1,100 + \$0 + \$800 \\ &= \$2,400 \end{aligned}$$

SOLVED PROBLEM 15.2

A defense contractor in Dallas has six jobs awaiting processing. Processing time and due dates are given in the table. Assume that jobs arrive in the order shown. Set the processing sequence according to FCFS and evaluate. Start date is day 1.

JOB	JOB PROCESSING TIME (DAYS)	JOB DUE DATE (DAYS)
A	6	22
B	12	14
C	14	30
D	2	18
E	10	25
F	4	34

SOLUTION

FCFS has the sequence A–B–C–D–E–F.

JOB SEQUENCE	JOB PROCESSING TIME	FLOW TIME	DUE DATE	JOB LATENESS
A	6	6	22	0
B	12	18	14	4
C	14	32	30	2
D	2	34	18	16
E	10	44	25	19
F	4	48	34	14
	48	182		55

1. Average completion time = $182/6 = 30.33$ days
2. Average number of jobs in system = $182/48 = 3.79$ jobs
3. Average job lateness = $55/6 = 9.16$ days
4. Utilization = $48/182 = 26.4\%$

SOLVED PROBLEM 15.3

The Dallas firm in Solved Problem 15.2 also wants to consider job sequencing by the SPT priority rule. Apply SPT to the same data, and provide a recommendation.

SOLUTION

SPT has the sequence D–F–A–E–B–C.

JOB SEQUENCE	JOB PROCESSING TIME	FLOW TIME	DUE DATE	JOB LATENESS
D	2	2	18	0
F	4	6	34	0
A	6	12	22	0
E	10	22	25	0
B	12	34	14	20
C	14	48	30	18
	48	124		38

1. Average completion time = $124/6 = 20.67$ days
2. Average number of jobs in system = $124/48 = 2.58$ jobs
3. Average job lateness = $38/6 = 6.33$ days
4. Utilization = $48/124 = 38.7\%$

SPT is superior to FCFS in this case on all four measures. If we were to also analyze EDD, we would, however, find its average job lateness to be lowest at 5.5 days. SPT is a good recommendation. SPT’s major disadvantage is that it makes long jobs wait, sometimes for a long time.

SOLVED PROBLEM 15.4

Use Johnson’s rule to find the optimum sequence for processing the jobs shown through two work centers. Times at each center are in hours.

JOB	WORK CENTER 1	WORK CENTER 2
A	6	12
B	3	7
C	18	9
D	15	14
E	16	8
F	10	15

SOLUTION

B	A	F	D	C	E
---	---	---	---	---	---

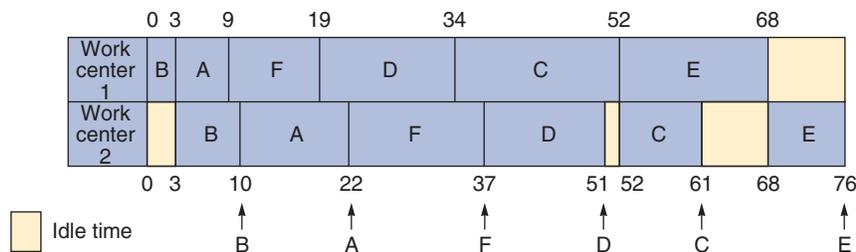
The sequential times are:

Work center 1	3	6	10	15	18	16
Work center 2	7	12	15	14	9	8

SOLVED PROBLEM 15.5

Illustrate the throughput time and idle time at the two work centers in Solved Problem 15.4 by constructing a time-phased chart.

SOLUTION



Problems

Note: **Px** means the problem may be solved with POM for Windows and/or Excel OM.

Problems 15.1–15.14 relate to Loading Jobs

•• **15.1** Ron Satterfield’s excavation company uses both Gantt scheduling charts and Gantt load charts.

a) Today, which is the end of day 7, Ron is reviewing the Gantt chart depicting these schedules:

- ◆ Job #151 was scheduled to begin on day 3 and to take 6 days. As of now, it is 1 day ahead of schedule.
- ◆ Job #177 was scheduled to begin on day 1 and take 4 days. It is currently on time.
- ◆ Job #179 was scheduled to start on day 7 and take 2 days. It actually got started on day 6 and is progressing according to plan.
- ◆ Job #211 was scheduled to begin on day 5, but missing equipment delayed it until day 6. It is progressing as expected and should take 3 days.
- ◆ Job #215 was scheduled to begin on day 4 and take 5 days. It got started on time but has since fallen behind 2 days.

Draw the Gantt scheduling chart for the activities above.

b) Ron now wants to use a Gantt load chart to see how much work is scheduled in each of his three work teams: Able, Baker, and Charlie. Five jobs constitute the current workload for these three work teams: Job #250, requiring 48 hours and #275 requiring 32 hours for Work Team Able; Jobs #210 and #280, requiring 16 and 24 hours, respectively, for Team Baker; and Job #225, requiring 40 hours, for Team Charlie.

Prepare the Gantt load chart for these activities.

•• **15.2** First Printing and Copy Center has 4 more jobs to be scheduled, in addition to those shown in Example 3 in the chapter. Production scheduling personnel are reviewing the Gantt chart at the end of day 4.

- ◆ Job D was scheduled to begin early on day 2 and to end on the middle of day 9. As of now (the review point after day 4), it is 2 days ahead of schedule.
- ◆ Job E should begin on day 1 and end on day 3. It is on time.
- ◆ Job F was to begin on day 3, but maintenance forced a delay of 1½ days. The job should now take 5 full days. It is now on schedule.
- ◆ Job G is a day behind schedule. It started at the beginning of day 2 and should require 6 days to complete.

Develop a Gantt schedule chart for First Printing and Copy Center.

• **15.3** The Green Cab Company has a taxi waiting at each of four cabstands in Evanston, Illinois. Four customers have called and requested service. The distances, in miles, from the waiting taxis to the customers are given in the following table. Find the optimal assignment of taxis to customers so as to minimize total driving distances to the customers.

CAB SITE	CUSTOMER			
	A	B	C	D
Stand 1	7	3	4	8
Stand 2	5	4	6	5
Stand 3	6	7	9	6
Stand 4	8	6	7	4

• **15.4** J.C. Howard’s medical testing company in Kansas wishes to assign a set of jobs to a set of machines. The following table provides the production data of each machine when performing the specific job:

JOB	MACHINE			
	A	B	C	D
1	7	9	8	10
2	10	9	7	6
3	11	5	9	6
4	9	11	5	8

a) Determine the assignment of jobs to machines that will maximize total production.

b) What is the total production of your assignments? **Px**

• **15.5** The Johnny Ho Manufacturing Company in Columbus, Ohio, is putting out four new electronic components. Each of Ho’s four plants has the capacity to add one more product to its current line of electronic parts. The unit-manufacturing costs for producing the different parts at the four plants are shown in the accompanying table. How should Ho assign the new products to the plants to minimize manufacturing costs?

ELECTRONIC COMPONENT	PLANT			
	1	2	3	4
C53	\$0.10	\$0.12	\$0.13	\$0.11
C81	0.05	0.06	0.04	0.08
D5	0.32	0.40	0.31	0.30
D44	0.17	0.14	0.19	0.15

• **15.6** Jamison Day Consultants has been entrusted with the task of evaluating a business plan that has been divided into four sections—marketing, finance, operations, and human resources. Chris, Steve, Juana, and Rebecca form the evaluation team. Each of them has expertise in a certain field and tends to finish that section faster. The estimated times taken by each team member for each section have been outlined in the table below. Further information states that each of these individuals is paid \$60/hour.

a) Assign each member to a different section such that Jamison Consultants’s overall cost is minimized.

b) What is the total cost of these assignments?

Times Taken by Team Members for Different Sections (minutes)

	MARKETING	FINANCE	OPERATIONS	HR
Chris	80	120	125	140
Steve	20	115	145	160
Juana	40	100	85	45
Rebecca	65	35	25	75

•• **15.7** The Baton Rouge Police Department has five detective squads available for assignment to five open crime cases. The chief of detectives, Jose Noguera, wishes to assign the squads so that the total time to conclude the cases is minimized. The average number of days, based on past performance, for each squad to complete each case is as follows:

SQUAD	CASE				
	A	B	C	D	E
1	14	7	3	7	27
2	20	7	12	6	30
3	10	3	4	5	21
4	8	12	7	12	21
5	13	25	24	26	8

Mikeledray/Shutterstock



Each squad is composed of different types of specialists, and whereas one squad may be very effective in certain types of cases, it may be almost useless in others.

- a) Solve the problem by using the assignment method.
- b) Assign the squads to the above cases, but with the constraint that squad 5 cannot work on case E because of a conflict. **Px**

• **15.8** Tigers Sports Club has to select four separate co-ed doubles teams to participate in an inter-club table tennis tournament. The pre-selection results in the selection of a group of four men—Raul, Jack, Gray, and Ajay—and four women—Barbara, Dona, Stella, and Jackie. Now, the task ahead lies in pairing these men and women in the best fashion. The table below shows a matrix that has been designed for this purpose, indicating how each of the men complements the game of each of the women. A higher score indicates a higher degree of compatibility in the games of the two individuals concerned. Find the best pairs.

Game Compatibility Matrix

	BARBARA	DONA	STELLA	JACKIE
Raul	30	20	10	40
Jack	70	10	60	70
Gray	40	20	50	40
Ajay	60	70	30	90

Px

••• **15.9** Daniel Glaser, chairman of the College of San Antonio’s business department, needs to assign professors to courses next semester. As a criterion for judging who should teach each course, Professor Glaser reviews the past 2 years’ teaching evaluations (which were filled out by students). Since each of the four professors taught each of the four courses at one time or another during the 2-year period, Glaser is able to record a course rating for each instructor. These ratings are shown in the following table.

- a) Find the assignment of professors to courses to maximize the overall teaching rating.
- b) Assign the professors to the courses with the exception that Professor Fisher cannot teach statistics. **Px**

PROFESSOR	COURSE			
	STATISTICS	MANAGEMENT	FINANCE	ECONOMICS
W. W. Fisher	90	65	95	40
D. Golhar	70	60	80	75
Z. Hug	85	40	80	60
N. K. Rustagi	55	80	65	55

•• **15.10** Lifang Wu owns an automated machine shop that makes precision auto parts. He has just compiled an input–output

report for the grinding work center. Complete this report and analyze the results.

Input–Output Report

PERIOD	1	2	3	4	TOTAL
Planned input	80	80	100	100	
Actual input	85	85	85	85	
Deviation					
Planned output	90	90	90	90	
Actual output	85	85	80	80	
Deviation					
Initial backlog: 30					

Additional problems 15.11–15.14 are available in MyOMLab.

Problems 15.15–15.25 relate to Sequencing Jobs

•• **15.15** The following jobs are waiting to be processed at the same machine center. Jobs are logged as they arrive:

JOB	DUE DATE	DURATION (DAYS)
A	313	8
B	312	16
C	325	40
D	314	5
E	314	3

In what sequence would the jobs be ranked according to the following decision rules: (a) FCFS, (b) EDD, (c) SPT, and (d) LPT? All dates are specified as manufacturing planning calendar days. Assume that all jobs arrive on day 275. Which decision is best and why? **Px**

•• **15.16** The following 5 overhaul jobs are waiting to be processed at Avianic’s Engine Repair Inc. These jobs were logged as they arrived. All dates are specified as planning calendar days. Assume that all jobs arrived on day 180; today’s date is 200.

JOB	DUE DATE	REMAINING TIME (DAYS)
103	214	10
205	223	7
309	217	11
412	219	5
517	217	15

Using the critical ratio scheduling rule, in what sequence would the jobs be processed? **Px**

•• **15.17** An Alabama lumberyard has four jobs on order, as shown in the following table. Today is day 205 on the yard’s schedule.

JOB	DUE DATE	REMAINING TIME (DAYS)
A	212	6
B	209	3
C	208	3
D	210	8

Px

In what sequence would the jobs be ranked according to the following decision rules:

- a) FCFS
- b) SPT
- c) LPT
- d) EDD
- e) Critical ratio

Which is best and why? Which has the minimum lateness?

•• **15.18** The following jobs are waiting to be processed at Rick Solano’s machine center. Solano’s machine center has a relatively

long backlog and sets a fresh schedule every 2 weeks, which does not disturb earlier schedules. Below are the jobs received during the previous 2 weeks. They are ready to be scheduled today, which is day 241 (day 241 is a work day). Job names refer to names of clients and contract numbers.

JOB	DATE JOB RECEIVED	PRODUCTION DAYS NEEDED	DATE JOB DUE
BR-02	228	15	300
CX-01	225	25	270
DE-06	230	35	320
RG-05	235	40	360
SY-11	231	30	310

- Complete the following table. (Show your supporting calculations.)
- Which dispatching rule has the best score for flow time?
- Which dispatching rule has the best score for utilization metric?
- Which dispatching rule has the best score for lateness?
- Which dispatching rule would you select? Support your decision.

DISPATCHING RULE	JOB SEQUENCE	FLOW TIME	UTILIZATION METRIC	AVERAGE NUMBER OF JOBS	AVERAGE LATENESS
EDD					
SPT					
LPT					
FCFS					

•• 15.19 The following jobs are waiting to be processed at Julie Morel’s machine center:

JOB	DATE ORDER RECEIVED	PRODUCTION DAYS NEEDED	DATE ORDER DUE
A	110	20	180
B	120	30	200
C	122	10	175
D	125	16	230
E	130	18	210

In what sequence would the jobs be ranked according to the following rules: (a) FCFS, (b) EDD, (c) SPT, and (d) LPT? All dates are according to shop calendar days. Today on the planning calendar is day 130, and none of the jobs have been started or scheduled. Which rule is best?

•• 15.20 Sunny Park Tailors has been asked to make three different types of wedding suits for separate customers. The table below highlights the time taken in hours for (1) cutting and sewing and (2) delivery of each of the suits. Which schedule finishes sooner: first come, first served (123) or a schedule using Johnson’s rule?

Times Taken for Different Activities (hours)

SUIT	CUT AND SEW	DELIVER
1	4	2
2	7	7
3	6	5

•• 15.21 The following jobs are waiting to be processed at Jeremy LaMontagne’s machine center. Today is day 250.

JOB	DATE JOB RECEIVED	PRODUCTION DAYS NEEDED	DATE JOB DUE
1	215	30	260
2	220	20	290
3	225	40	300
4	240	50	320
5	250	20	340

Using the critical ratio scheduling rule, in what sequence would the jobs be processed?

••• 15.22 The following set of seven jobs is to be processed through two work centers at George Heinrich’s printing company. The sequence is first printing, then binding. Processing time at each of the work centers is shown in the following table:

JOB	PRINTING (HOURS)	BINDING (HOURS)
T	15	3
U	7	9
V	4	10
W	7	6
X	10	9
Y	4	5
Z	7	8

- What is the optimal sequence for these jobs to be scheduled?
- Chart these jobs through the two work centers.
- What is the total length of time of this optimal solution?
- What is the idle time in the binding shop, given the optimal solution?
- How much would the binding machine’s idle time be cut by splitting Job Z in half?

••• 15.23 Six jobs are to be processed through a two-step operation. The first operation involves sanding, and the second involves painting. Processing times are as follows:

JOB	OPERATION 1 (HOURS)	OPERATION 2 (HOURS)
A	10	5
B	7	4
C	5	7
D	3	8
E	2	6
F	4	3

Determine a sequence that will minimize the total completion time for these jobs. Illustrate graphically.

Additional problems 15.24–15.25 are available in MyOMLab.

Problems 15.26–15.27 relate to Scheduling Services

•• 15.26 Daniel’s Barber Shop at Newark Airport is open 7 days a week but has fluctuating demand. Daniel Ball is interested in treating his barbers as well as he can with steady work and preferably 5 days of work with two consecutive days off. His analysis of his staffing needs resulted in the following plan. Schedule Daniel’s staff with the minimum number of barbers.

	DAY						
	MON.	TUE.	WED.	THU.	FRI.	SAT.	SUN.
Barbers needed	6	5	5	5	6	4	3

•• 15.27 Given the following demand for waiters and waitresses at S. Ghosh Bar and Grill, determine the minimum wait staff needed with a policy of 2 consecutive days off.

	DAY						
	MON.	TUE.	WED.	THU.	FRI.	SAT.	SUN.
Wait staff needed	3	4	4	5	6	7	4

CASE STUDIES

Old Oregon Wood Store

In 2015, George Wright started the Old Oregon Wood Store to manufacture Old Oregon tables. Each table is carefully constructed by hand using the highest-quality oak. Old Oregon tables can support more than 500 pounds, and since the start of the Old Oregon Wood Store, not one table has been returned because of faulty workmanship or structural problems. In addition to being rugged, each table is beautifully finished using a urethane varnish that George developed over 20 years of working with wood-finishing materials.

The manufacturing process consists of four steps: preparation, assembly, finishing, and packaging. Each step is performed by one person. In addition to overseeing the entire operation, George does all of the finishing. Tom Surowski performs the preparation step, which involves cutting and forming the basic components of the tables. Leon Davis is in charge of the assembly, and Cathy Stark performs the packaging.

Although each person is responsible for only one step in the manufacturing process, everyone can perform any one of the steps. It is George's policy that occasionally everyone should complete several tables on his or her own without any help or assistance. A small competition is used to see who can complete an entire table in the least amount of time. George maintains average total and intermediate completion times. The data are shown in Figure 15.7.

Preparation	100	Assembly	160	Finishing	250	Packaging	275
(Tom)							
Preparation	80	Assembly	160	Finishing	220	Packaging	230
(George)							
Preparation	110	Assembly	200	Finishing	280	Packaging	290
(Leon)							
Preparation	120	Assembly	190	Finishing	290	Packaging	315
(Cathy)							

Figure 15.7

Manufacturing Time in Minutes

Preparation	110	Assembly	190	Finishing	290	Packaging	300
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Figure 15.8

Randy's Completion Times in Minutes

It takes Cathy longer than the other employees to construct an Old Oregon table. In addition to being slower than the other employees, Cathy is also unhappy about her current responsibility of packaging, which leaves her idle most of the day. Her first preference is finishing, and her second preference is preparation.

In addition to quality, George is concerned with costs and efficiency. When one of the employees misses a day, it causes major scheduling problems. In some cases, George assigns another employee overtime to complete the necessary work. At other times, George simply waits until the employee returns to work to complete his or her step in the manufacturing process. Both solutions cause problems. Overtime is expensive, and waiting causes delays and sometimes stops the entire manufacturing process.

To overcome some of these problems, Randy Lane was hired. Randy's major duties are to perform miscellaneous jobs and to help out if one of the employees is absent. George has given Randy training in all phases of the manufacturing process, and he is pleased with the speed at which Randy has been able to learn how to completely assemble Old Oregon tables. Randy's average total and intermediate completion times are given in Figure 15.8.

Discussion Questions

1. What is the fastest way to manufacture Old Oregon tables using the original crew? How many could be made per day?
2. Would production rates and quantities change significantly if George would allow Randy to perform one of the four functions and make one of the original crew the backup person?
3. What is the fastest time to manufacture a table with the original crew if Cathy is moved to either preparation or finishing?
4. Whoever performs the packaging function is severely underutilized. Can you find a better way of utilizing the four- or five-person crew than either giving each a single job or allowing each to manufacture an entire table? How many tables could be manufactured per day with this scheme?

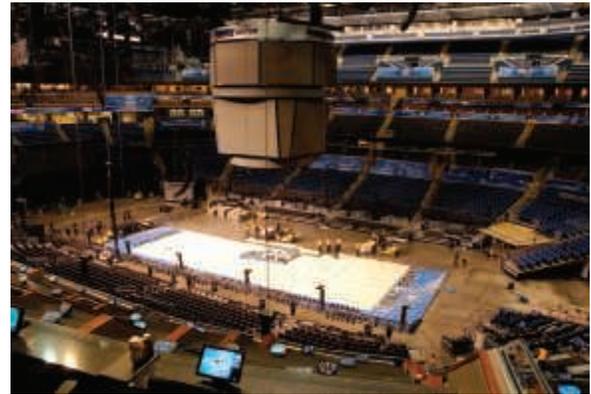
From the Eagles to the Magic: Converting the Amway Center

Video Case 

The massive 875,000-square-foot Amway Center in Orlando, Florida, is a state-of-the-art sports entertainment center. While it is the home of the Orlando Magic basketball team, it is a flexible venue designed to accommodate a vast array of entertainment. The facility is used for everything from a concert by the Eagles or Britney Spears, to ice hockey, to arena football, to conventions, as well as 41 regular season home games played by its major tenant, the National Basketball Association’s Orlando Magic.

The building is a LEED-certified (Leadership in Energy and Environmental Design), sustainable, environmentally friendly design, with unmatched technology. Dispersed throughout the building are over 1,000 digital monitors, the latest in broadcasting technology, and the tallest high-definition video board in an NBA venue. To fully utilize this nearly \$500 million complex, conversions from one event to the next must be done rapidly—often in a matter of hours. Letting the facility sit idle because of delays in conversion is not an option.

Well-executed conversions help maximize facility revenue and at the same time minimize expenses. Fast and efficient conversions are critical. Like any other process, a conversion can be analyzed and separated into its component activities, each requiring its own human and capital resources. The operations manager must determine when to do the conversion, how to train and schedule the crew, which tools and capital equipment are necessary, and the specific steps necessary to break down the current event and set up for the next. In addition to trying to maintain a stable crew (typically provided by local staffing companies) and to maintain



Fernando Medina

control during the frenzied pace of a conversion, managers divide the workforce into cross-trained crews, with each crew operating in its own uniquely colored shirt.

At the Amway Center, Charlie Leone makes it happen. Charlie is the operations manager, and as such, he knows that any conversion is loaded with complications and risks. Concerts add a special risk because each concert has its own idiosyncrasies—and the breakdown for the Eagles concert will be unique. Charlie and his crews must anticipate and eliminate any potential problems. Charlie’s immediate issue is making a schedule for converting the Eagles’ concert venue to an NBA basketball venue. The activities and the time for various tasks have been determined and are shown in Table 15.3.

TABLE 15.3 CONCERT-TO-BASKETBALL CONVERSION TASKS

Available crew size = 16, including two fork truck drivers

TIME ALLOWED	TASKS	CREW AND TIME REQUIRED
3 to 4 hr	11:20 PM Performance crew begins teardown of concert stage & equipment	Concert’s Responsibility
45 min	11:20 PM Clear Floor Crew Get chair carts from storage	10 for 15 min
	Clear all chairs on floor, loading carts starting at south end, working north	16 for 30 min
	Move chair carts to north storage and stack as they become full	(includes 1 fork truck operator)
15 min	11:50 PM (Or as soon as area under rigging is cleared) Set up retractable basketball seating on north end	6 for 15 min
	Take down railing above concert stage	
	Place railings on cart and move to storage	
2.5 hr	12:05 AM Basketball Floor Crew Position 15 basketball floor carts on floor	8
	Mark out arena floor for proper placement of basketball floor	
	Position basketball floor by section	
	Assemble/join flooring/lay carpets over concrete	
	Position basketball nets in place	
	Set up scorer tables	
	Install risers for all courtside seating	
	Install 8-ft tables on east side of court	
2.5 hr	Seating Unit Crew Starts same time as Basketball Floor Crew Set up retractable basketball seating on north end	8
	Set up retractable basketball seating on south end	(includes 2 fork truck operators)
	(Can only be done after concert stage and equipment is out of way)	
	Install stairs to Superstar Seating	
2 hr	Board Crew Starts after Seating Unit Crew finishes Install dasher board on south end	4
	Move stairs to storage	

(Continued)

TABLE 15.3 Continued

TIME ALLOWED	TASKS	CREW AND TIME REQUIRED
2 hr	Chair Crew Starts after Seating Unit Crew finishes Get chair carts from storage Position chair carts on floor Position chairs behind goals, courtside, and scorer tables Clean, sweep, and place carts in order	12
45 min	End-of-Shift Activities Starts after Chair Crew finishes Perform checklist items Ensure that steps and stairways and railings are in place and tight Check all seats are in upright position and locked in place Report any damaged seats or armrests in need of repair Verify exact number of chairs behind goals, courtside, and scorer tables	12
15 min	Check Out Starts after End-of-Shift Activities Check for next conversion date and time and inform crew Report any injuries Punch out all employees before leaving 8:00 AM Floor ready for Magic practice	16

Discussion Questions*

1. Make a Gantt chart to help Charlie organize his crew to perform the concert-to-basketball conversion. *Note:* Do not include the teardown of the concert stage and equipment, as that is the responsibility of the concert crew.

2. What time will the floor be ready?
3. Does Charlie have any extra personnel or a shortage of personnel? If so how many?

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

Scheduling at Hard Rock Cafe**Video Case** 

Whether it's scheduling nurses at Mayo Clinic, pilots at Southwest Airlines, classrooms at UCLA, or servers at a Hard Rock Cafe, it's clear that good scheduling is important. Proper schedules use an organization's assets (1) more effectively, by serving customers promptly, and (2) more efficiently, by lowering costs.

Hard Rock Cafe at Universal Studios, Orlando, is the world's largest restaurant, with 1,100 seats on two main levels. With typical turnover of employees in the restaurant industry at 80% to 100% per year, Hard Rock General Manager Ken Hoffman takes scheduling very seriously. Hoffman wants his 160 servers to be effective, but he also wants to treat them fairly. He has done so with scheduling software and flexibility that has increased productivity while contributing to turnover that is half the industry average. His goal is to find the fine balance that gives employees financially productive daily work shifts while setting the schedule tight enough so as to not overstaff between lunch and dinner.

The weekly schedule begins with a sales forecast. "First, we examine last year's sales at the cafe for the same day of the week," says Hoffman. "Then we adjust our forecast for this year based on a variety of closely watched factors. For example, we call the Orlando Convention Bureau every week to see what major groups will be in town. Then we send two researchers out to check on the occupancy of nearby hotels. We watch closely to see what

concerts are scheduled at Hard Rock Live—the 3,000-seat concert stage next door. From the forecast, we calculate how many people we need to have on duty each day for the kitchen, the bar, as hosts, and for table service."

Once Hard Rock determines the number of staff needed, servers submit request forms, which are fed into the software's linear programming mathematical model. Individuals are given priority rankings from 1 to 9, based on their seniority and how important they are to fill each day's schedule. Schedules are then posted by day and by workstation. Trades are handled between employees, who understand the value of each specific shift and station.

Hard Rock employees like the system, as does the general manager, since sales per labor-hour are rising and turnover is dropping.

Discussion Questions*

1. Name and justify several factors that Hoffman could use in forecasting weekly sales.
2. What can be done to lower turnover in large restaurants?
3. Why is seniority important in scheduling servers?
4. How does the schedule impact productivity?

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

- **Additional Case Study:** Visit [MyOMLab](#) for this free case study:

Payroll Planning, Inc.: Describes setting a schedule for handling the accounting for dozens of client firms.

Endnotes

1. Opportunity costs are those profits forgone or not obtained.
2. Finite capacity scheduling (FCS) systems go by a number of names, including finite scheduling and advance planning systems

(APS). The name manufacturing execution systems (MES) may also be used, but MES tends to suggest an emphasis on the reporting system from shop operations back to the scheduling activity.

Chapter 15 *Rapid Review*

Main Heading	Review Material	MyOMLab
THE IMPORTANCE OF SHORT-TERM SCHEDULING (p. 602)	<p>The strategic importance of scheduling is clear:</p> <ul style="list-style-type: none"> Effective scheduling means <i>faster movement</i> of goods and services through a facility. This means greater use of assets and hence greater capacity per dollar invested, which, in turn, <i>lowers cost</i>. Added capacity, faster throughput, and the related flexibility mean better customer service through <i>faster delivery</i>. Good scheduling contributes to realistic commitments, hence <i>dependable delivery</i>. 	Concept Questions: 1.1–1.2
SCHEDULING ISSUES (pp. 602–605)	<p><i>The objective of scheduling is to allocate and prioritize demand (generated by either forecasts or customer orders) to available facilities.</i></p> <ul style="list-style-type: none"> Forward scheduling—Begins the schedule as soon as the requirements are known. Backward scheduling—Begins with the due date by scheduling the final operation first and the other job steps in reverse order. Loading—The assigning of jobs to work or processing centers. <p>The four scheduling criteria are (1) <i>minimize completion time</i>, (2) <i>maximize utilization</i>, (3) <i>minimize work-in-process (WIP) inventory</i>, and (4) <i>minimize customer waiting time</i>.</p>	Concept Questions: 2.1–2.4 VIDEO 15.1 From the Eagles to the Magic: Converting the Amway Center
SCHEDULING PROCESS-FOCUSED FACILITIES (p. 605)	<p>A process-focused facility is a high-variety, low-volume system commonly found in manufacturing and services. It is also called an intermittent, or job shop, facility.</p>	Concept Questions: 3.1–3.4
LOADING JOBS (pp. 605–610)	<ul style="list-style-type: none"> Input–output control—A system that allows operations personnel to manage facility work flows by tracking work added to a work center and its work completed. ConWIP cards—Cards that control the amount of work in a work center, aiding input/output control. <p>ConWIP is an acronym for <i>constant work-in-process</i>. A ConWIP card travels with a job (or batch) through the work center. When the job is finished, the card is released and returned to the initial workstation, authorizing the entry of a new batch into the work center.</p> <ul style="list-style-type: none"> Gantt charts—Planning charts used to schedule resources and allocate time. <p>The Gantt <i>load chart</i> shows the loading and idle times of several departments, machines, or facilities. It displays the relative workloads in the system so that the manager knows what adjustments are appropriate.</p> <p>The Gantt <i>schedule chart</i> is used to monitor jobs in progress (and is also used for project scheduling). It indicates which jobs are on schedule and which are ahead of or behind schedule.</p> <ul style="list-style-type: none"> Assignment method—A special class of linear programming models that involves assigning tasks or jobs to resources. <p>In assignment problems, only one job (or worker) is assigned to one machine (or project).</p> <p>The assignment method involves adding and subtracting appropriate numbers in the table to find the lowest <i>opportunity cost</i> for each assignment.</p>	Concept Questions: 4.1–4.4 Problems: 15.1–15.14 Virtual Office Hours for Solved Problem: 15.1
SEQUENCING JOBS (pp. 611–617)	<ul style="list-style-type: none"> Sequencing—Determining the order in which jobs should be done at each work center. Priority rules—Rules used to determine the sequence of jobs in process-oriented facilities. First come, first served (FCFS)—Jobs are completed in the order in which they arrived. Shortest processing time (SPT)—Jobs with the shortest processing times are assigned first. Earliest due date—Earliest due date jobs are performed first. Longest processing time (LPT)—Jobs with the longest processing time are completed first. 	Concept Questions: 5.1–5.4 Problems: 15.15–15.25 Virtual Office Hours for Solved Problems: 15.2–15.5 ACTIVE MODEL 15.1
	$\text{Average completion time} = \frac{\text{Sum of total flow time}}{\text{Number of jobs}} \quad (15-1)$	
	$\text{Utilization metric} = \frac{\text{Total job work (processing) time}}{\text{Sum of total flow time}} \quad (15-2)$	

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	<p>Average number of jobs in the system = $\frac{\text{Sum of total flow time}}{\text{Total job work (processing) time}}$ (15-3)</p> <p>Average job lateness = $\frac{\text{Total late days}}{\text{Number of jobs}}$ (15-4)</p> <p>Job lateness = $\text{Max}\{0, \text{yesterday} + \text{flow time} - \text{due date}\}$ (15-5)</p> <p>SPT is the best technique for minimizing job flow and average number of jobs in the system.</p> <p>FCFS performs about average on most criteria, and it appears fair to customers.</p> <p>EDD minimizes maximum tardiness.</p> <ul style="list-style-type: none"> ▪ Flow time—The time each job spends waiting plus the time being processed. ▪ Critical ratio (CR)—A sequencing rule that is an index number computed by dividing the time remaining until due date by the work time remaining: $\text{CR} = \frac{\text{Time remaining}}{\text{Workdays remaining}} = \frac{\text{Due date} - \text{Today's date}}{\text{Work (lead) time remaining}} \quad (15-6)$ <p>As opposed to the priority rules, the critical ratio is dynamic and easily updated. It tends to perform better than FCFS, SPT, EDD, or LPT on the average job-lateness criterion.</p> <ul style="list-style-type: none"> ▪ Johnson's rule—An approach that minimizes processing time for sequencing a group of jobs through two work centers while minimizing total idle time in the work centers. <p>Rule-based scheduling systems have the following limitations: (1) Scheduling is dynamic, (2) rules do not look upstream or downstream, and (3) rules do not look beyond due dates.</p>	
FINITE CAPACITY SCHEDULING (FCS) (pp. 617–618)	<ul style="list-style-type: none"> ▪ Finite capacity scheduling (FCS)—Computerized short-term scheduling that overcomes the disadvantage of rule-based systems by providing the user with graphical interactive computing. 	Concept Questions: 6.1–6.2
SCHEDULING SERVICES (pp. 618–621)	<p>Cyclical scheduling with inconsistent staffing needs is often the case in services. The objective focuses on developing a schedule with the minimum number of workers. In these cases, each employee is assigned to a shift and has time off.</p>	Concept Questions: 7.1–7.4 VIDEO 15.2 Scheduling at Hard Rock Cafe Problems: 15.26–15.27

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 15.1** Which of the following decisions covers the longest time period?
- Short-term scheduling
 - Capacity planning
 - Aggregate planning
 - A master schedule
- LO 15.2** A visual aid used in loading and scheduling jobs is a:
- Gantt chart.
 - planning file.
 - bottleneck.
 - load-schedule matrix.
 - level material chart.
- LO 15.3** The assignment method involves adding and subtracting appropriate numbers in the table to find the lowest _____ for each assignment.
- profit
 - number of steps
 - number of allocations
 - range per row
 - opportunity cost
- LO 15.4** The most popular priority rules include:
- FCFS.
 - EDD.
 - SPT.
 - all of the above.
- LO 15.5** The job that should be scheduled last when using Johnson's rule is the job with the:
- largest total processing time on both machines.
 - smallest total processing time on both machines.
 - longest activity time if it lies with the first machine.
 - longest activity time if it lies with the second machine.
 - shortest activity time if it lies with the second machine.
- LO 15.6** What is computerized short-term scheduling that overcomes the disadvantage of rule-based systems by providing the user with graphical interactive computing?
- LPT
 - FCS
 - CSS
 - FCFS
 - GIC
- LO 15.7** Cyclical scheduling is used to schedule:
- jobs.
 - machines.
 - shipments.
 - employees.

Answers: LO 15.1. b; LO 15.2. a; LO 15.3. e; LO 15.4. d; LO 15.5. e; LO 15.6. b; LO 15.7. d.