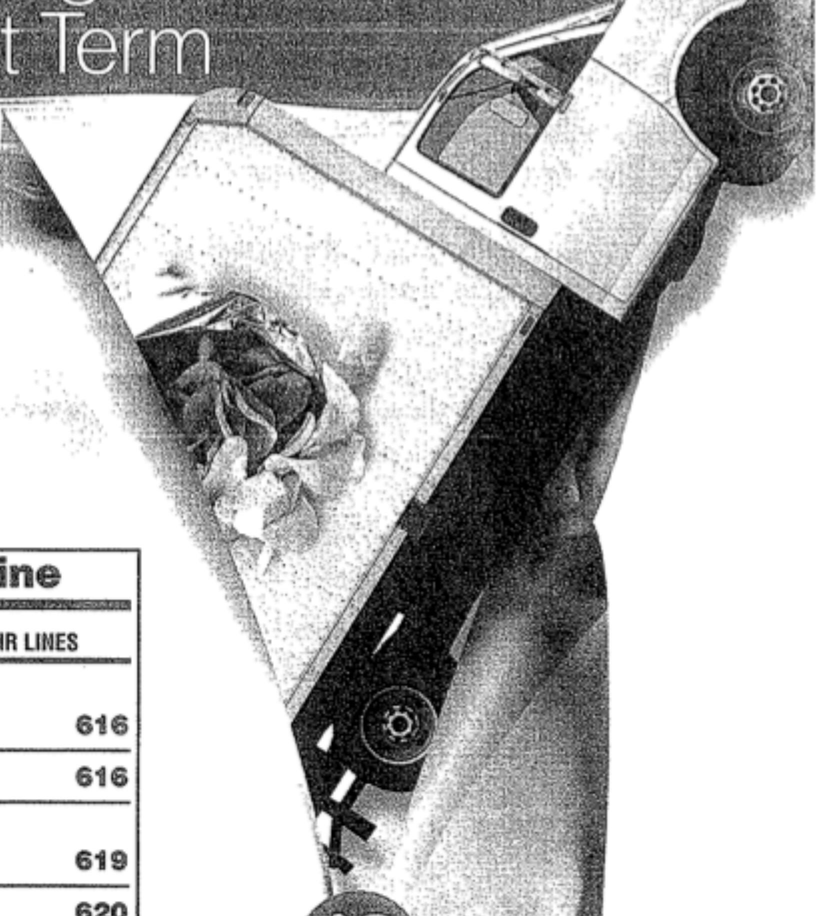
15 Scheduling for the Short Term



Chapter Outline

10

OM Strategy Decisions

- Design of Goods and Services
- Managing Quality
- Process Strategy
- Location Strategies
- Layout Strategies
- Human Resources
- Supply-Chain Management
- Inventory Management
- **Scheduling**
  - Aggregate
  - Short-Term
- Maintenance

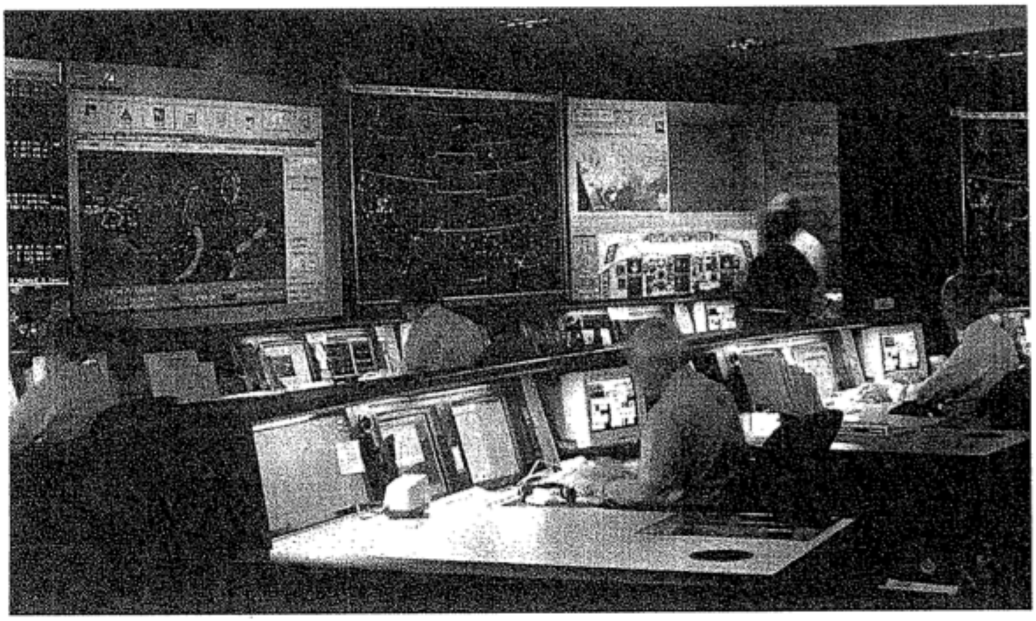
SCHEDULING AIRPLANES WHEN WEATHER IS THE ENEMY

Operations managers at airlines learn to expect the unexpected. Events that require rapid rescheduling are a regular part of life. Throughout the ordeals of tornadoes, ice storms, and snowstorms, airlines across the globe struggle to cope with delays, cancellations, and furious passengers. The inevitable changes to the schedule often create a ripple effect that impacts passengers at dozens of airports in the network. Close to 10% of Delta Air Lines's flights are disrupted in a typical year, half because of weather; the cost is $440 million in lost revenue, overtime pay, and food and lodging vouchers.

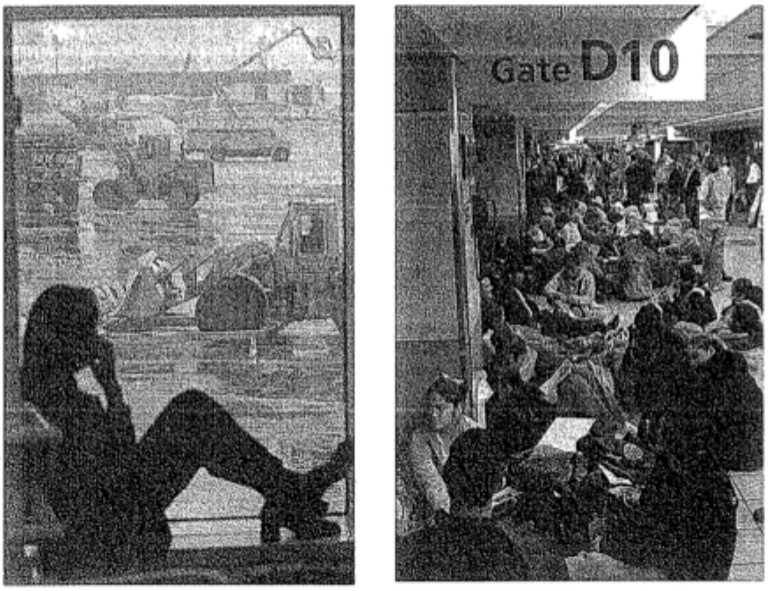
Now Delta is taking the sting out of the scheduling nightmares that come from weather-related problems with its $33-million high-tech nerve center adjacent to the Hartsfield-Jackson Atlanta International Airport. From computers to telecommunications systems to deicers, Delta's Operations Control Center more quickly

4 A.M.	**10 A.M.**	**1:30 P.M.**	**5 P.M.**	**10 P.M.**
FORECAST: Rain with a chance of light snow for Atlanta.	FORECAST: Freezing rain after 5 P.M.	FORECAST: Rain changing to snow.	FORECAST: Less snow than expected.	FORECAST: Snow tapering off.
ACTION: Discuss status of planes and possible need for cancellations.	ACTION: Ready deicing trucks; develop plans to cancel 50% to 80% of flights after 6 P.M.	ACTION: Cancel half the flights from 6 P.M. to 10 A.M.; notify passengers and reroute planes.	ACTION: Continue calling passengers and arrange alternate flights.	ACTION: Find hotels for 1,600 passengers stranded by the storm.

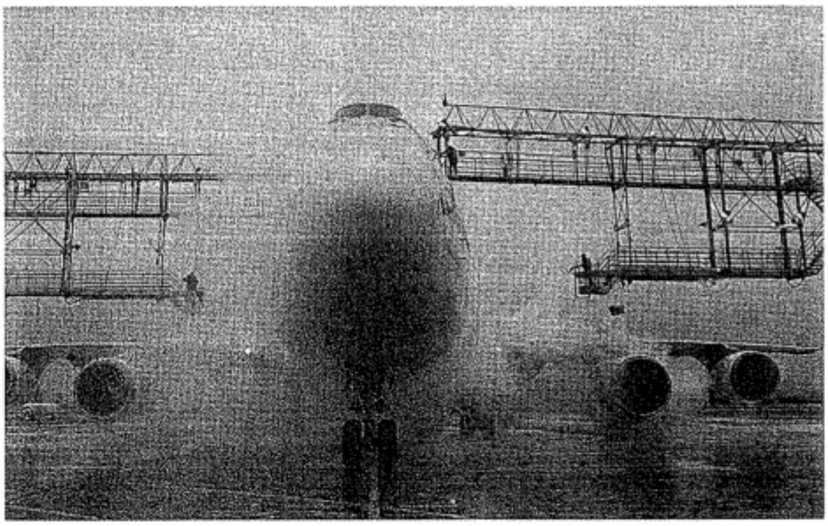
Here is what Delta officials had to do one December day when a storm bore down on Atlanta.



To improve flight rescheduling efforts, Delta employees monitor giant screens that display meteorological charts, weather patterns, and maps of Delta flights at its Operations Control Center in Atlanta.



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



In an effort to maintain schedules, Delta Air Lines uses elaborate equipment as shown here for ice removal.

notifies customers of schedule changes, reroutes flights, and gets jets into the air. The Operations Control Center's job is to keep flights flowing as smoothly as possible in spite of the disruptions.

With earlier access to information, the center's staff of 18 pores over streams of data transmitted by computers and adjusts to changes quickly. Using mathematical scheduling models described in this chapter, Delta decides on schedule and route changes. This means coordinating incoming and outgoing aircraft, ensuring that the right crews are on hand, rescheduling connections to coordinate arrival times, and making sure information gets to passengers as soon as possible.

Delta's software, called the Inconvenienced Passenger Rebooking System, notifies passengers of cancellations or delays, and even books them onto rival airlines if necessary. With 150,000 passengers flying into and out of Atlanta every day, Delta estimates its scheduling efforts save $35 million a year.

Chapter 15 Learning Objectives

AUTHOR COMMENT Good scheduling means lower costs and faster and more dependable delivery.

THE IMPORTANCE OF SHORT-TERM SCHEDULING

Delta Air Lines doesn't schedule just its 753 aircraft every day. It also schedules over 10,000 pilots and flight attendants to accommodate passengers who wish to reach their destinations. This schedule, based on huge computer programs, plays a major role in satisfying customers. Delta finds competitive advantage with its flexibility for last-minute adjustments to demand and weather disruptions.

Manufacturing firms also make schedules that match production to customer demands. Lockheed Martin's Dallas plant schedules machines, tools, and people to make aircraft parts. Lockheed's mainframe computer downloads schedules for parts production into a flexible machining system (FMS) in which a manager makes the final scheduling decision. The FMS allows parts of many sizes or shapes to be made, in any order. This scheduling versatility results in parts produced on a just-in-time basis, with low setup times, little work-in-process, and high machine utilization. Efficient scheduling is how companies like Lockheed Martin meet due dates promised to customers and face time-based competition.

The strategic importance of scheduling is clear:

- Effective scheduling means faster movement of goods and services through a facility. This means greater use of assets and hence greater capacity per dollar invested, which, in turn, *lowers cost.*
- Added capacity, faster throughput, and the related flexibility mean better customer service through *faster delivery.*
- Good scheduling also contributes to realistic commitments and hence *dependable delivery.*

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

SCHEDULING ISSUES

Scheduling deals with the timing of operations. The types of scheduling decisions made in five organizations—a hospital, a college, a manufacturer, a restaurant, and an airline—are shown in Table 15.1. As you can see from Figure 15.1, a sequence of decisions affects scheduling. Schedule decisions begin with *capacity* planning, which involves *total facility and equipment resources available* (discussed in Chapter 7 and Supplement 7). Capacity plans are usually annual or quarterly as new equipment and facilities are purchased or discarded. Aggregate planning (Chapter 13) makes decisions regarding the use of facilities, inventory, people, and outside contractors. Aggregate plans are typically monthly, and *resources are allocated in terms of an aggregate measure such as total units, tons, or shop hours.* However, the master schedule breaks down the aggregate plan and develops a *schedule for specific products or product lines for each week.* Short-term schedules then translate capacity decisions, aggregate (intermediate) planning, and master schedules into job sequences and *specific assignments of personnel, materials, and machinery.* In this chapter, we describe the narrow issue of scheduling goods and services in the *short run* (that is, matching daily or hourly requirements to specific personnel and equipment).

LO1: Explain the relationship between short-term scheduling, capacity planning, aggregate planning, and a master schedule

The objective of scheduling is to allocate and prioritize demand (generated by either forecasts or customer orders) to available facilities. Two significant factors in achieving this allocation and prioritizing are (1) the type of scheduling, forward or backward, and (2) the criteria for priorities. We discuss these two topics next.

Organization	Managers Schedule the Following:
Arnold Palmer Hospital	Operating room use Patient admissions Nursing, security, maintenance staffs Outpatient treatments
University of Missouri	Classrooms and audiovisual equipment Student and instructor schedules Graduate and undergraduate courses
Lockheed Martin factory	Production of goods Purchases of materials Workers
Hard Rock Cafe	Chef, waiters, bartenders Delivery of fresh foods Entertainers Opening of dining areas
Delta Air Lines	Maintenance of aircraft Departure timetables Flight crews, catering, gate, and ticketing personnel

◄ **TABLE 15.1**
Scheduling Decisions

VIDEO 15.1
Scheduling at Hard Rock

▼ **FIGURE 15.1 The Relationship between Capacity Planning, Aggregate Planning, Master Schedule, and Short-Term Scheduling for a Bike Co.**

Capacity Planning
(Long term; years)
Changes in Facilities
Changes in Equipment
See Chapter 7 and Supplement 7

Capacity Plan for New Facilities
Adjust capacity to the demand suggested by strategic plan

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

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

Master Production Schedule for Bike Models
(Determine weekly capacity schedule)

	Month 1				Month 2			
Week	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	

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

Work Assigned to Specific Personnel and Work Centers
Make finite capacity schedule by matching specific tasks to specific people and machines

Assemble Model 22 in work center 6

Forward and Backward Scheduling

Scheduling involves assigning due dates to specific jobs, but many jobs compete simultaneously for the same resources. To help address the difficulties inherent in scheduling, we can categorize scheduling techniques as (1) forward scheduling and (2) backward scheduling.

Forward scheduling
Scheduling that begins the schedule as soon as the requirements are known.

Forward scheduling starts the schedule as soon as the job requirements are known. Forward scheduling is used in a variety of organizations such as hospitals, clinics, fine-dining restaurants, and machine tool manufacturers. In these facilities, jobs are performed to customer order, and delivery is often requested as soon as possible. Forward scheduling is usually designed to produce a schedule that can be accomplished even if it means not meeting the due date. In many instances, forward scheduling causes a buildup of work-in-process inventory.

Backward scheduling
Scheduling that begins with the due date and schedules the final operation first and the other job steps in reverse order.

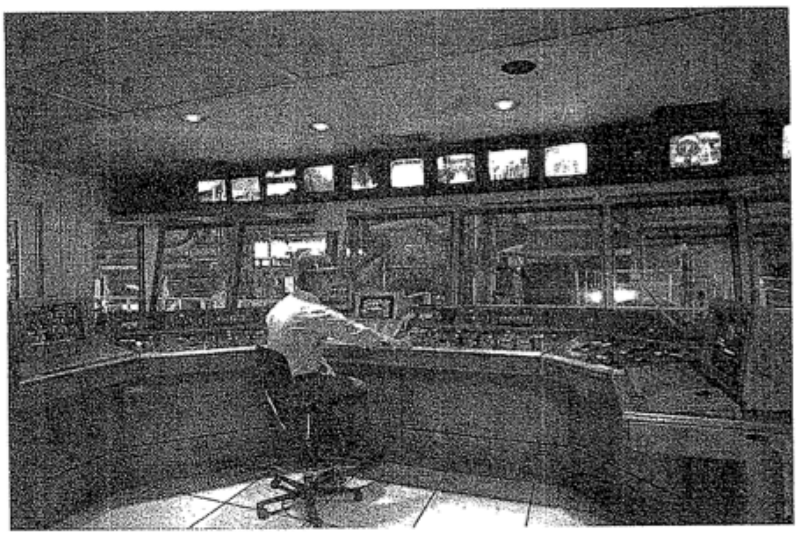
Backward scheduling begins with the due date, scheduling the *final* operation first. Steps in the job are then scheduled, one at a time, in reverse order. By subtracting the lead time for each item, the start time is obtained. However, the resources necessary to accomplish the schedule may not exist. Backward scheduling is used in many 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 what can be achieved and customer due dates.

Machine breakdowns, absenteeism, quality problems, shortages, and other factors further complicate scheduling. (See the *OM in Action* box "Scheduling Workers Who Fall Asleep Is a Killer—Literally.") 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.

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. These four criteria are:

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



U.S. Steel maintains its world-class operation by automating the scheduling of people, machines, and tools through its cold-reduction-mill control room. Computerized scheduling software helps managers monitor production.

OM in Action ► Scheduling Workers Who Fall Asleep Is a Killer—Literally

The accidents at the nuclear plants at Three Mile Island, Pennsylvania, and Chernobyl, Russia, and the disaster at Bhopal, India, all had one thing in common: they occurred between midnight and 4:00 A.M. These facilities had other problems, but the need for sleep simply results in unreliable workplace performance. In some cases, unable to cope with a constantly changing work schedule, workers just plain fall asleep.

The same is true for pilots. Their inconsistent schedules and long flights often force them to snooze in the cockpit to get enough sleep. (Delta's flight from Atlanta to Mumbai, India, for example, takes about 18 hours.) The Bombardier regional jet flying from Honolulu to Hilo, Hawaii, encountered a serious problem in 2008 as it flew over Maui: both pilots were so fast asleep that they failed to respond to frantic calls from air-traffic controllers for 18 minutes. (The plane, with 40 passengers, overshot its destination as it flew 26 miles over the Pacific.) One FedEx pilot even complained of falling asleep while taxiing to take off.

Millions of people work in industries that maintain round-the-clock schedules. Employees from graveyard shifts report tales of seeing sleeping assembly-line workers fall off their stools, batches of defective parts sliding past dozing inspectors, and exhausted forklift operators crashing into walls. Virtually all shift workers are sleep deprived. And the National Highway Traffic Safety Administration indicates that drowsiness may be a factor in as many as 100,000 crashes annually.

Scheduling is a major problem in firms with 24/7 shifts, but some managers are taking steps to deal with schedule-related sleep problems among workers. Motorola, Dow Chemical, Detroit Edison, Pennzoil, and Exxon, for instance, all give workers several days off between shift changes.

Operations managers can make shift work less dangerous with shifts that do not exceed 12 hours, that encourage 8 hours of sleep each day, and that have extended time off between shift changes. As more is learned about the economic toll of non-daytime schedules and changing schedules, companies are learning to improve scheduling.

Sources: The Wall Street Journal (September 12, 2008): A1, A14 and (October 25, 2009): A:1; and *Air Safety and Health* (January 2004): 14.

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

Table 15.2 provides an overview of different processes and approaches to scheduling.

We now examine scheduling in process-focused facilities, in repetitive facilities, and in the service sector.

SCHEDULING PROCESS-FOCUSED FACILITIES

AUTHOR COMMENT
The facilities discussed here are built around processes.

Process-focused facilities (also known as *intermittent* or *job-shop facilities*),[1] as we see in Table 15.2, are high-variety, low-volume systems commonly found in manufacturing and service organizations. These are production systems in which products are made to order. Items made under this system usually differ considerably in terms of materials used, order of processing, processing requirements, time of processing, and setup requirements. Because of these differences, scheduling can be complex. To run a facility in a balanced and efficient manner, the manager needs a production planning and control system. This system should:

- Schedule incoming orders without violating capacity constraints of individual work centers.
- Check the availability of tools and materials before releasing an order to a department.
- Establish due dates for each job and check progress against need dates and order lead times.
- Check work in progress as jobs move through the shop.
- Provide feedback on plant and production activities.
- Provide work efficiency statistics and monitor operator times for payroll and labor distribution analyses.

[1]Much of the literature on scheduling is about manufacturing; therefore, the traditional term *job-shop scheduling* is often used.

TABLE 15.2 Different Processes Suggest Different Approaches to Scheduling

Process-focused facilities (job shops)
- Focus is on generating a forward-looking schedule.
- MRP generates due dates that are refined with finite capacity scheduling techniques.
- *Examples:* foundries, machine shops, cabinet shops, print shops, many restaurants, and the fashion industry.

Work cells (focused facilities that process families of similar components)
- Focus is on generating a forward-looking schedule.
- MRP generates due dates, and subsequent detail scheduling/dispatching is done at the work cell with kanbans and priority rules.
- *Examples:* work cells at ambulance manufacturer Wheeled Coach, aircraft engine rebuilder Standard Aero, greeting-card maker Hallmark.

Repetitive facilities (assembly lines)
- Focus is on generating a forward-looking schedule that is achieved by balancing the line with traditional assembly-line techniques.
- Pull techniques, such as JIT and kanban, signal component scheduling to support the assembly line.
- Challenging scheduling problems typically occur only when the process is new or when products or models change.
- *Examples:* assembly lines for a wide variety of products from autos to home appliances and computers.

Product-focused facilities (continuous)
- Focus is on generating a forward-looking schedule that can meet a reasonably stable demand with the existing fixed capacity.
- Capacity in such facilities is usually limited by long-term capital investment.
- Capacity is usually known, as is the setup and run time for the limited range of products.
- *Examples:* facilities with very high volume production and limited-variety products such as paper on huge machines at International Paper, beer in a brewery at Anheuser-Busch, or rolled steel in a Nucor plant.

Whether the scheduling system is manual or automated, it must be accurate and relevant. This means it requires a production database with both planning and control files. Three types of planning files are:

1. An *item master file*, which contains information about each component the firm produces or purchases.
2. A *routing file*, which indicates each component's flow through the shop.
3. A *work-center master file*, which contains information about the work center, such as capacity and efficiency.

Control files track the actual progress made against the plan for each work order.

LOADING JOBS

Loading
The assigning of jobs to work or processing centers.

Loading means the assignment of jobs to work or processing centers. 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.[2] 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
A system that allows operations personnel to manage facility work flows by tracking work added to a work center and its work completed.

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

[2]Note that this discussion can apply to facilities that might be called a "shop" in a manufacturing firm, a "unit" in a hospital, or a "department" in an office or a large kitchen.

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.

EXAMPLE 1

Input-output control

DNC Machining, Inc., manufactures driveway security fences and gates. It wants to develop an input–output control report for the aluminum machining 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 ▶ DNC uses schedule information to create Figure 15.2, which monitors the workload-capacity relationship at 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.

◀ FIGURE 15.2
Input–Output Control

Work Center DNC Milling (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		

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)

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

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 ▶ 15.21

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.

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

The options available to operations personnel to manage facility work flow include the following:

1. Correcting performances
2. Increasing capacity
3. Increasing or reducing input to the work center by (a) routing work to or from other work centers, (b) increasing or decreasing subcontracting, (c) producing less (or producing more)

Producing less is not a popular solution, but the advantages can be substantial. First, customer-service levels may improve because units may be produced on time. Second, efficiency may actually improve because there is less work in process cluttering the work center and adding to overhead costs. Third, quality may improve because less work-in-process hides fewer problems.

Gantt Charts

Gantt charts
Planning charts used to schedule resources and allocate time.

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.

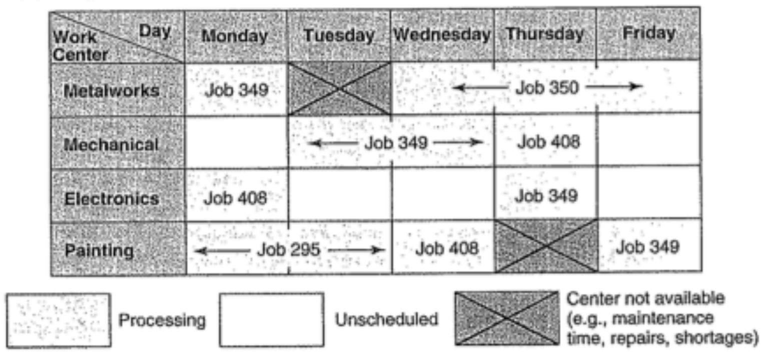
EXAMPLE 2 ▶
Gantt load chart

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



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

LO2: Draw Gantt loading and scheduling charts

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.

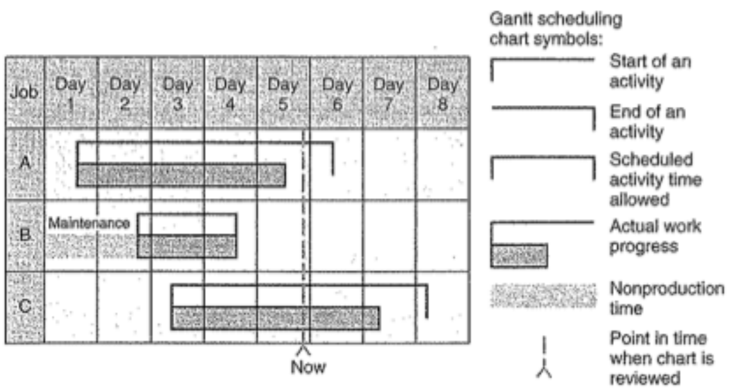
EXAMPLE 3

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 a Printing Firm

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

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).

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

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.

LO3: Apply the assignment method for loading jobs

	Typesetter		
Job	**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*[3] 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

[3]Opportunity costs are those profits forgone or not obtained.

column. This step has the effect of reducing the numbers in the table until a series 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

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

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

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 / JOB	A	B	C
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 / JOB	A	B	C
R-34	3	4	0
S-66	0	0	
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, 15.4, 15.5, 15.6, 15.7, 15.8, 15.9

EXCEL OM Data File **Ch15Ex4.xls** can be found at **www.pearsonglobaleditions.com/heizer.**

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, ranging from coast-to-coast time changes, airline flight schedules, and night games running late. The league strives to achieve these 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 problem formulation, the time it takes the league to generate a schedule has been significantly decreased, and the quality of the schedule has improved.

AUTHOR COMMENT
Once jobs are loaded, managers must decide the sequence in which they are to be completed.

SEQUENCING JOBS

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 they arrived.

Shortest processing time (SPT)
Jobs with the shortest processing times are assigned first.

Earliest due date (EDD)
Earliest due date jobs are performed first.

Longest processing time (LPT)
Jobs with the longest processing time are completed first.

Scheduling provides a basis for assigning jobs to work centers. *Loading* is a capacity-control technique that highlights overloads and underloads. **Sequencing** (also referred to as dispatching) specifies the order in which jobs should be done at each center. For example, suppose that 10 patients are assigned to a medical clinic for treatment. In what order should they be treated? Should the first patient to be served be the one who arrived first or the one who needs emergency treatment? Sequencing methods provide such guidelines. These methods are referred to as priority rules for sequencing or dispatching jobs to work centers.

Priority Rules for Dispatching Jobs

Priority rules provide guidelines for the sequence in which jobs should be worked. The rules are especially applicable for process-focused facilities such as clinics, print shops, and manufacturing job shops. We will examine a few of the most popular priority rules. Priority rules try to minimize completion time, number of jobs in the system, and job lateness while maximizing facility utilization.

The most popular priority rules are:

- **FCFS: first come, first served.** The first job to arrive at a work center is processed first.
- **SPT: shortest processing time.** The shortest jobs are handled first and completed.
- **EDD: earliest due date.** The job with the earliest due date is selected first.
- **LPT: longest processing time.** The longer, bigger jobs are often very important and are selected first.

Example 5 compares these rules.

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.

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. The "flow time" in the system for this sequence measures the time each job spends waiting plus time being processed. Job B, for example, waits 6 days while job A is being processed, then takes 2 more days of operation time itself; so it will be completed in 8 days—which is 2 days later than its due date.

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 first-come, first-served rule results in the following measures of effectiveness:

a. Average completion time $= \dfrac{\text{Sum of total flow time}}{\text{Number of jobs}}$

$$= \frac{77 \text{ days}}{5} = 15.4 \text{ days}$$

b. Utilization metric $= \dfrac{\text{Total job work (processing) time}}{\text{Sum of total flow time}}$

$$= \frac{28}{77} = 36.4\%$$

c. Average number of jobs in the system $= \dfrac{\text{Sum of total flow time}}{\text{Total job work (processing) time}}$

$$= \frac{77 \text{ days}}{28 \text{ days}} = 2.75 \text{ jobs}$$

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

a. Average completion time $= \dfrac{65}{3} = 13$ days

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

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

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

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

LO4: Name and describe each of the priority sequencing rules

Measurements of effectiveness for EDD are:

a. Average completion time $= \dfrac{68}{5} = 13.6$ days

b. Utilization metric $= \dfrac{28}{68} = 41.2\%$

c. Average number of jobs in the system $= \dfrac{68}{28} = 2.43$ jobs

d. Average job lateness $= \dfrac{6}{5} = 1.2$ 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 ▶ 15.10, 15.12a–d, 15.13, 15.14

EXCEL OM Data File **Ch15Ex5.xls** can be found at **www.pearsonglobaleditions.com/heizer.**

ACTIVE MODEL 15.1 This example is further illustrated in Active Model 15.1 at **www.pearsonglobaleditions.com/heizer.**

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.

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?

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.

Another type of sequencing rule is the critical ratio. 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:

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

Example 6 shows how to use the critical ratio.

◄ EXAMPLE 6
Critical ratio

Today is day 25 on Zyco 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 ▶ 15.11, 15.12e, 15.16

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. Relate both make-to-stock and make-to-order jobs on a common basis.
4. Adjust priorities (and revise schedules) automatically for changes in both demand and job progress.
5. Dynamically track job progress.

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

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.

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. This is called the *N*/2 problem.

Johnson's rule can be used to minimize the processing 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.

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 processing time for the five jobs.

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.

				A

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.

B				A

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

LO5: Use Johnson's rule

B			C	A

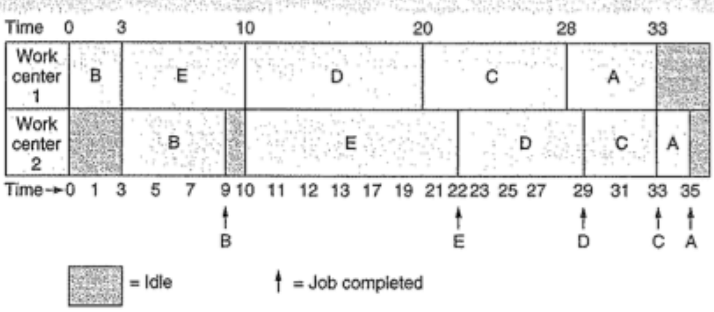
4. There is a tie (at 7 hours) for the shortest remaining job. We can place E, which was on the first work center, first. Then D is placed in the last sequencing position.

B	E	D	C	A

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 ▶ 15.15, 15.17, 15.18

Limitations of Rule-Based Dispatching 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.

2. Rules do not look upstream or downstream; idle resources and bottleneck resources in other departments may not be recognized.
3. 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.

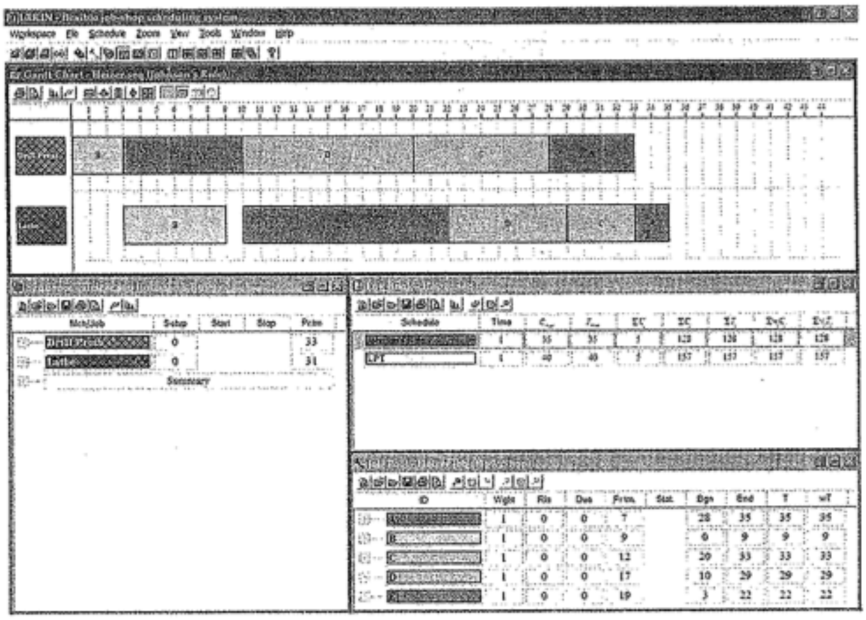
Despite these limitations, schedulers often use sequencing rules such as SPT, EDD, or critical ratio. They apply these methods at each work center and then modify the sequence to deal with a multitude of real-world variables. They may do this manually or with finite capacity scheduling software.

FINITE CAPACITY SCHEDULING (FCS)

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

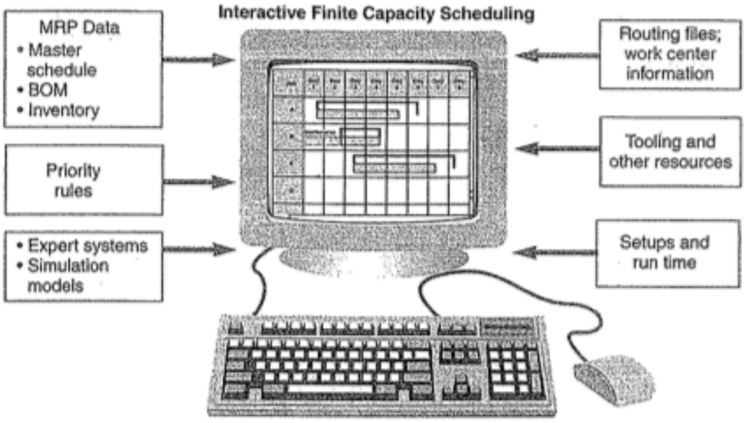
Short-term scheduling is also called finite capacity scheduling.[4] **Finite capacity scheduling (FCS)** overcomes the disadvantages of systems based exclusively on rules by providing the scheduler with interactive computing and graphic output. In dynamic scheduling environments such as job shops (with a high variety, low volume, and shared resources) we expect changes—but changes disrupt schedules. Therefore, 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.

LO6: Define finite capacity scheduling



This Lekin® finite capacity scheduling software presents a schedule of the five jobs and the two work centers shown in Example 7 (pages 630–631) in Gantt chart form. The software is capable of using a variety of priority rules, several shop types, up to 50 jobs, 20 work centers, and 100 machines to generate a schedule. The Lekin software is available for free at **www.stern.nyc.edu/om/software/lekin/download/html** and can solve many of the problems at the end of this chapter.

[4]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.



◄ **FIGURE 15.5**
Finite Capacity Scheduling Systems Combine MRP and Shop Floor Production Data to Generate a Gantt Chart That Can Be Manipulated by the User on a Computer Screen

The initial data for finite scheduling systems is often the output from an MRP system. The output from MRP systems is traditionally in weekly "buckets" that have no capacity constraint. These systems just tell the planner when the material is needed, ignoring the capacity issue. Because *infinite*-size buckets are unrealistic and inadequate for detail scheduling, MRP data require refinement. MRP output is combined with routing files, due dates, capacity of work centers, tooling, and other resource availability to provide the data needed for effective FCS. These are the same data needed in any manual system, but FCS software formalizes them, speeds analysis, and makes changes easier. The combining of MRP 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, ProPlanner, Preactor, Asprova, Tactic, and Jobplan are currently used at over 60% of U.S. plants.

SCHEDULING REPETITIVE FACILITIES

AUTHOR COMMENT Repetitive producers create forward-looking schedules with level material use.

The scheduling goals defined at the beginning of this chapter are also appropriate for repetitive production. You may recall from Chapter 7 that repetitive producers make standard products from modules. The usual approach is to develop a forward-looking schedule on a balanced assembly line. (Refer to Table 15.2 on page 620).

Repetitive producers want to satisfy customer demands, lower inventory investment, and reduce the batch (or lot) size, with existing equipment and processes. A technique to move toward these goals is to use a level-material-use schedule. **Level material use** means frequent, high-quality, small lot sizes that contribute to just-in-time production. This is exactly what world-class producers such as Harley-Davidson, John Deere, and Johnson Controls do. The advantages of level material use are:

Level material use
The use of frequent, high-quality, small lot sizes that contribute to just-in-time production.

1. Lower inventory levels, which releases capital for other uses
2. Faster product throughput (that is, shorter lead times)
3. Improved component quality and hence improved product quality
4. Reduced floor-space requirements
5. Improved communication among employees because they are closer together (which can result in improved teamwork and *esprit de corps*)
6. Smoother production process because large lots have not "hidden" the problems

Suppose a repetitive producer runs large monthly batches: With a level-material-use schedule, management would move toward shortening this monthly cycle to a weekly, daily, or even hourly cycle.

One way to develop a level-material-use schedule is to first determine the minimum lot size that will keep the production process moving. This is illustrated in the next chapter, "JIT and Lean Operations."

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

SCHEDULING SERVICES

Scheduling service systems differs from scheduling manufacturing systems in several ways:

- 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, behavioral, social, seniority, and status issues complicate scheduling.

The following examples note the complexity of scheduling services.

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. However, they do schedule products (such as surgeries) just like a factory, and capacities must 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, Target, and Radio Shack. These systems track individual store sales, transactions, units sold, and customer traffic in 15-minute increments to create work schedules. Walmart's 1.3 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.

Airlines Airlines face two constraints when scheduling flight crews: (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. Airline planners must build crew schedules that meet or exceed crews' pay guarantees. Planners must also make efficient use of their other expensive resource: aircraft. These schedules are typically built using linear programming models. The *OM in Action* box "Scheduling Aircraft Turnaround" details how very short-term schedules (20 minutes) can help an airline become more efficient.

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.

OM in Action ▶ Scheduling Aircraft Turnaround

Airlines that face increasingly difficult financial futures have recently discovered the importance of efficient scheduling of ground turnaround activities for flights. For some low-cost, point-to-point carriers like Southwest Airlines, scheduling turnarounds in 20 minutes has been standard policy for years. Yet for others, like Continental, United, and US Airways, the approach is new. This figure illustrates how US Airways deals with speedier schedules. Now its planes average seven trips a day, instead of six, meaning the carrier can sell tens of thousands more seats a day. And with this improved scheduling, its punctuality moved from near the bottom in 2007 to virtually tie Southwest for first place 2 years later.

▶ US Airways has cut the turnaround time on commercial flights from the current 45 minutes to 20 minutes for Boeing 737s. To the right is a list of procedures that must be completed before the flight can depart:

1. Ticket agent takes flight plan to pilot, who loads information into aircraft computer. About 130 passengers disembark from the plane.
2. Workers clean trash cans, seat pockets, lavatories, etc.
3. Catering personnel board plane and replenish supply of drinks and ice.
4. A fuel truck loads up to 5,300 gallons of fuel into aircraft's wings.
5. Baggage crews unload up to 4,000 pounds of luggage and 2,000 pounds of freight. "Runners" rush the luggage to baggage claim area in terminal.
6. Ramp agents, who help park aircraft upon arrival, "push" plane back away from gate.

Sources: US Airways, Boeing, *The Wall Street Journal* (January 6, 2009): D8; and *Aviation Week & Space Technology* (January 29, 2001): 50.

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. The *OM in Action* box "Scheduling for Peaks by Swapping Employees" provides yet another example of flexibility in scheduling.

OM in Action ▶ Scheduling for Peaks by Swapping Employees

When calls to Choice Hotel International's reservation line surged after a recent ad campaign, Choice V.P. Don Brockwell found his call center short-staffed. So he quickly arranged to add 20 agents per shift—but not by hiring or calling a temp service. Instead, the additional workers were employees of 1-800-Flowers.com. Choice and Flowers's unusual deal helps both reduce reliance on outsourcers. It also bolsters recruiting and retention because call center workers have more varied work and are less subject to a seasonal business cycle.

The deal works in part because Choice's high season is mid-May through early October, while Flowers's call volume increases between October and May, with surges at Christmas, Valentine's Day, and Mother's Day. The companies typically lend each other as many as 100 employees, for weeks at a time, in the three call centers they share. But some workers might even change assignments in the middle of a shift. Most employees like the variety. "When you sit down and sell hotel rooms for 8 hours a day, selling flowers is a nice break," says Rick Hilliner, a former teacher, now at the Grand Junction, Colorado, center.

Sources: The Wall Street Journal (April 10, 2006): B3; and *Call Center Magazine* (March 2005): 18–24.

Scheduling Service Employees with Cyclical Scheduling

A number of techniques and algorithms exist for scheduling service-sector employees such as 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*.

LO7: Use the cyclical scheduling technique

Cyclical Scheduling Cyclical scheduling with inconsistent staffing needs is often the case in services such as restaurants and police work. Here 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. 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 workweek 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. Determine the necessary daily staffing requirements. Doris has done this:

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 ▶ 15.19, 15.20

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.

CHAPTER 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, repetitive, 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 to heuristics and linear programming approaches for matching capacity to demand in service environments.

Key Terms

Forward scheduling (p. 618)
Backward scheduling (p. 618)
Loading (p. 620)
Input–output control (p. 620)
ConWIP cards (p. 621)
Gantt charts (p. 622)
Assignment method (p. 623)
Sequencing (p. 626)
Priority rules (p. 626)
First come, first served (FCFS) (p. 626)
Shortest processing time (SPT) (p. 626)
Earliest due date (EDD) (p. 626)
Longest processing time (LPT) (p. 626)
Critical ratio (CR) (p. 629)
Johnson's rule (p. 630)
Finite capacity scheduling (FCS) (p. 632)
Level material use (p. 633)

Ethical Dilemma

Scheduling people to work second and third shifts (evening and "graveyard") is a problem in almost every 24-hour company. The *OM in Action* box "Scheduling Workers Who Fall Asleep Is a Killer—Literally," on page 619, describes potentially dangerous issues on the night shift at FedEx and a nuclear power plant. Perhaps even more significantly, 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 A.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?

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 of level material flow?
13. What is input–output control?

Using Software for Short-Term Scheduling

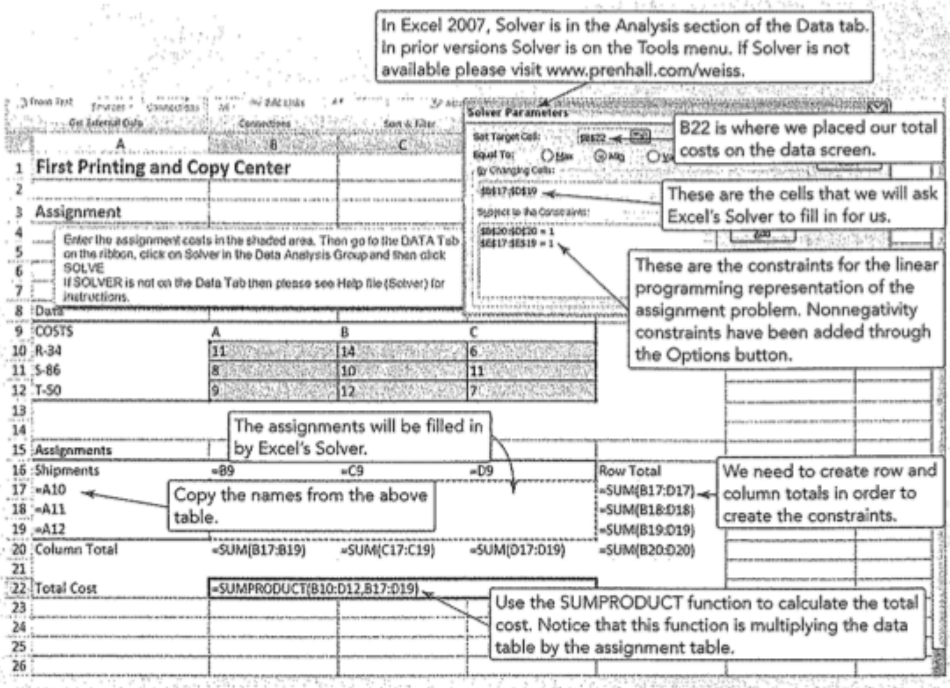
In addition to the commercial software we noted in this chapter, short-term scheduling problems can be solved with the Excel OM software that comes free at our website **www.pearsonglobaleditions.com/heizer**. POM for Windows also includes a scheduling module. The use of each of these programs is explained 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 Tools command, followed by the Solver command. Excel's Solver uses linear programming to optimize assignment problems. The constraints are also shown in Program 15.1. We then select the Solve command and the solution appears in Program 15.2.

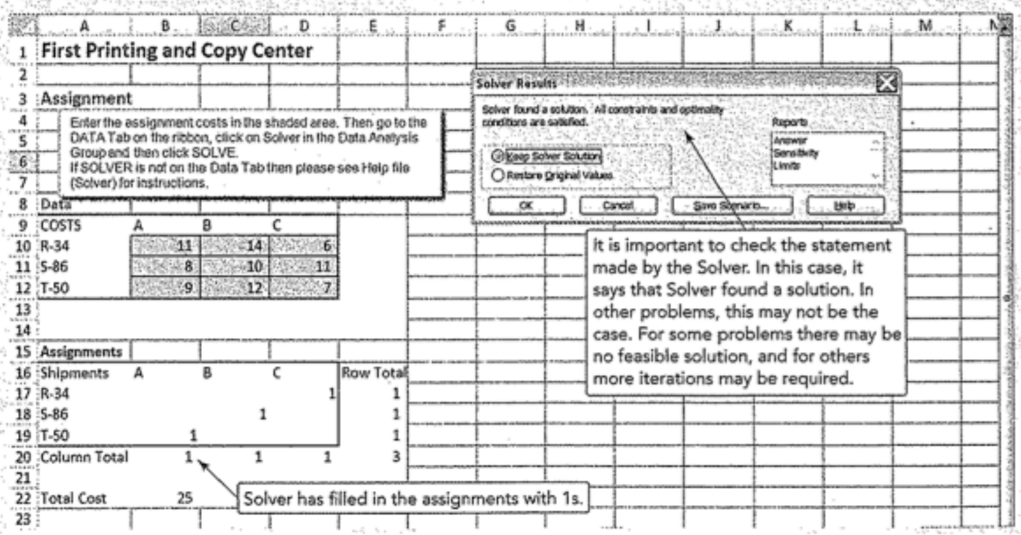
Excel OM's Job Shop Scheduling module is illustrated in Program 15.3. Program 15.3 uses Example 5's data. Because jobs are listed in the sequence in which they arrived (see column A), the results are for the FCFS rule. Program 15.3 also shows some of the formulas (columns F, G, H, I, J) used in the calculations.

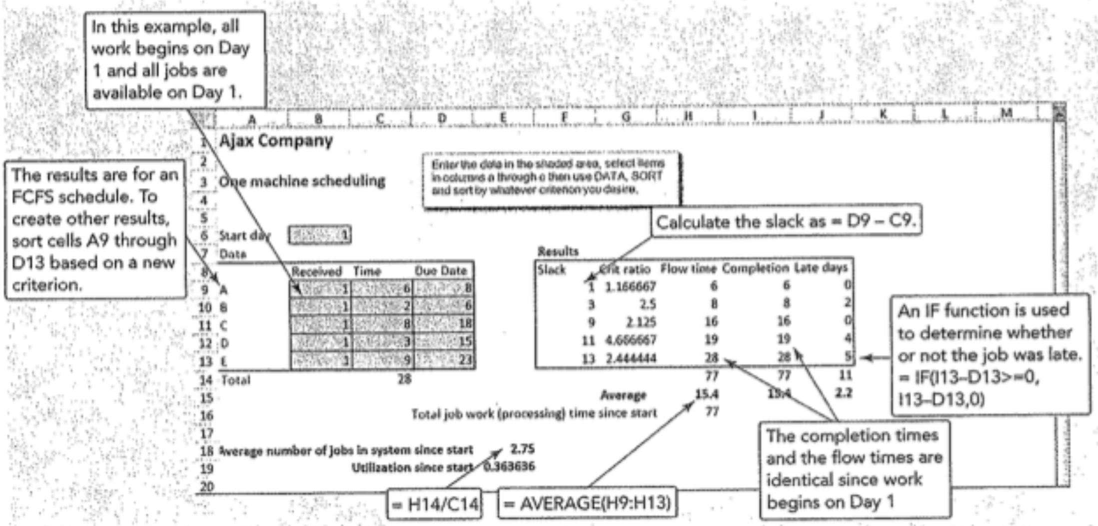
To solve with the SPT rule, we need four intermediate steps: (1) Select (that is, highlight) the data in columns A, B, C for all jobs; (2) invoke the Data command; (3) invoke the Sort command; and (4) sort by Time (column C) in *ascending* order. To solve for EDD, step 4 changes to sort by Due Date (column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



▲ **PROGRAM 15.1 Excel OM's Assignment Module Using Example 4's Data**
After entering the problem data in the yellow area, select Tools, then Solver.

▼ **PROGRAM 15.2 Excel OM Output Screen for Assignment Problem Described in Program 15.1**





▲ **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 at www.pearsonglobaleditions.com/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?

HIREE \ OFFICE	OMAHA	MIAMI	DALLAS
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.

HIREE \ OFFICE	OMAHA	MIAMI	DALLAS	NEW YORK
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

(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):

HIREE \ OFFICE	OMAHA	MIAMI	DALLAS	NEW YORK
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

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

▼ 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.

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

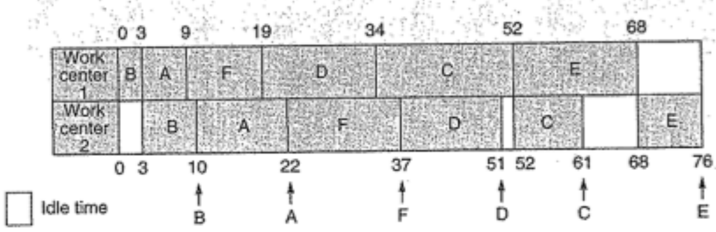
The sequential times are:

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*

•• **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 work load 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 was 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 Orange Top 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.

	Customer			
Cab Site	**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

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

• **15.4** Molly Riggs's medical testing company 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:

	Machine			
Job	**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?

• **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	Plant			
Component	**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** Claire 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 Claire 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 Akron Police Department has five detective squads available for assignment to five open crime cases. The chief of detectives, Paul Kuzdrall, 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:

	Case				
Squad	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

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.

• **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

••• **15.9** James Gross, chairman of the College of Oshkosh's business department, needs to assign professors to courses next semester. As a criterion for judging who should teach each course, Professor Gross 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, Gross 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.

	Course			
Professor	**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** 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?

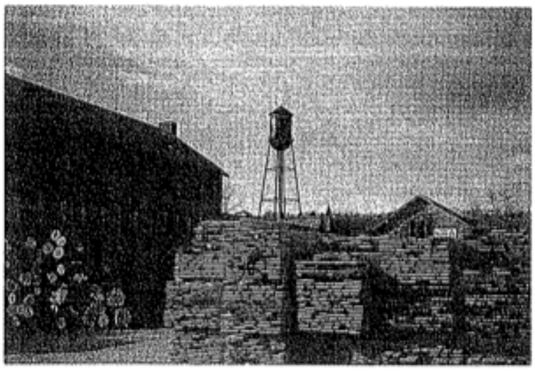
• **15.11** The following 5 overhaul jobs are waiting to be processed at Avianic's Engine Repair Inc. These jobs were logged as they arrived. All dates are specified as planning calendar days. Assume that all jobs arrived on day 180; today's date is 200.

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?

•• **15.12** 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



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?

•• **15.13** The following jobs are waiting to be processed at Rick Carlson's machine center. Carlson's machine center has a relatively long backlog and sets fresh schedules every 2 weeks, which do 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

a) Complete the table below. (Show your supporting calculations.)
b) Which dispatching rule has the best score for flow time?
c) Which dispatching rule has the best score for utilization metric?
d) Which dispatching rule has the best score for lateness?
e) 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					

•• **15.14** 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?

•• **15.15** 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

•• **15.16** 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?

•••• **15.17** 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

a) What is the optimal sequence for these jobs to be scheduled?
b) Chart these jobs through the two work centers.

c) What is the total length of time of this optimal solution?
d) What is the idle time in the binding shop, given the optimal solution?
e) How much would the binding machine's idle time be cut by splitting Job Z in half? P/X

••• **15.18** 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. P/X

•• **15.19** Jesse's Barber Shop at O'Hare Airport is open 7 days a week but has fluctuating demand. Jesse 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 Jesse'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

•• **15.20** 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

•• **15.21** 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					

▶ **Refer to MyOMLab for these additional homework problems: 15.22–15.27**

Case Studies

▶ Old Oregon Wood Store

In 2010, 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 15.6.

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 15.7.

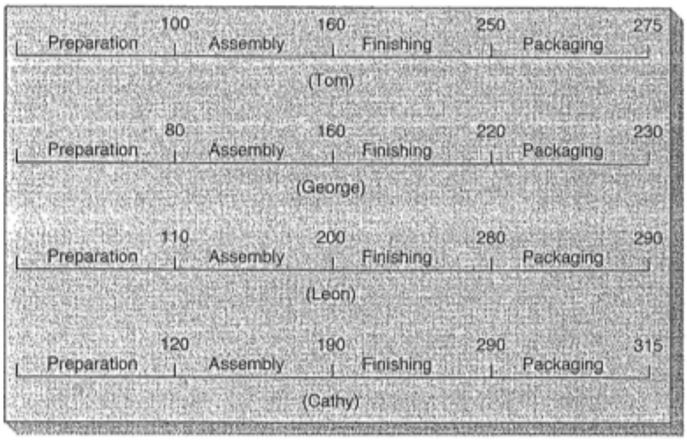


FIGURE 15.6 **Manufacturing Time in Minutes**

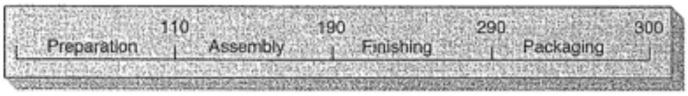


FIGURE 15.7 **Randy's Completion Times in Minutes**

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?

▶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 on productivity?

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

▶**Additional Case Study:** Visit **www.pearsonglobaleditions.com/myomlab** or **www.pearsonglobaleditions.com/heizer** for this free case study: **Payroll Planning, Inc.:** Describes setting a schedule for handling the accounting for dozens of client firms.

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Chapter 15 **Rapid Review**

Main Heading	Review Material	myomlab
THE IMPORTANCE OF SHORT-TERM SCHEDULING (p. 616)	The strategic importance of scheduling is clear: • Effective scheduling means *faster movement* of goods and services through a facility. This means greater use of assets and hence greater capacity per dollar invested, which, in turn, *lowers cost*. • Added capacity, faster throughput, and the related flexibility mean better customer service through *faster delivery*. • Good scheduling contributes to realistic commitments, hence *dependable delivery*.	
SCHEDULING ISSUES (pp. 616–619)	*The objective of scheduling is to allocate and prioritize demand (generated by either forecasts or customer orders) to available facilities.* ▪ **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. The four scheduling criteria are (1) *minimize completion time*, (2) *maximize utilization*, (3) *minimize work-in-process (WIP) inventory*, and (4) *minimize customer waiting time*.	**VIDEO 15.1** Scheduling at Hard Rock
SCHEDULING PROCESS-FOCUSED FACILITIES (pp. 619–620)	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. Control files track the actual progress made against the plan for each work order.	
LOADING JOBS (pp. 620–625)	▪ **Loading**—The assigning of jobs to work or processing centers. ▪ **Input/output control**—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. ConWIP is an acronym for *constant work-in-process*. 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. ▪ **Gantt charts**—Planning charts used to schedule resources and allocate time. The Gantt *load chart* 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. The 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. ▪ **Assignment method**—A special class of linear programming models that involves assigning tasks or jobs to resources. In assignment problems, only one job (or worker) is assigned to one machine (or project). The assignment method involves adding and subtracting appropriate numbers in the table to find the lowest *opportunity cost* for each assignment.	Problems: 15.1–15.9, 15.21 Virtual Office Hours for Solved Problems: 15.1
SEQUENCING JOBS (pp. 626–632)	▪ **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: $\text{Average completion time} = \frac{\text{Sum of total flow time}}{\text{Number of jobs}}$ $\text{Utilization metric} = \frac{\text{Total job work (processing) time}}{\text{Sum of total flow time}}$	Problems: 15.10–15.18 Virtual Office Hours for Solved Problems: 15.2–15.5 **ACTIVE MODEL 15.1**

myomlab

Main Heading	Review Material
	$$\text{Average number of jobs in the system} = \frac{\text{Sum of total flow time}}{\text{Total job work (processing) time}}$$ $$\text{Average job lateness} = \frac{\text{Total late days}}{\text{Number of jobs}}$$ SPT is the best technique for minimizing job flow and average number of jobs in the system. FCFS performs about average on most criteria, and it appears fair to customers. EDD minimizes maximum tardiness. ■ **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: $$CR = \frac{\text{Time remaining}}{\text{Workdays remaining}} = \frac{\text{Due date} - \text{Today's date}}{\text{Work (lead) time remaining}}$$ 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. ■ **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. 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.
FINITE CAPACITY SCHEDULING (FCS) (pp. 632–633)	• **Finite capacity scheduling (FCS)**—Computerized short-term scheduling that overcomes the disadvantage of rule-based systems by providing the user with graphical interactive computing.
SCHEDULING REPETITIVE FACILITIES (pp. 633–634)	• **Level material use**—The use of frequent, high-quality, small lot sizes that contribute to just-in-time production. Advantages of level material use are (1) lower inventory levels, (2) faster product throughput, (3) improved component and product quality, (4) reduced floor-space requirements, (5) improved communication among employees, and (6) a smoother production process.
SCHEDULING SERVICES (pp. 634–637)	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. Problems: 15.19–15.20

Self Test

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

LO1. Which of the following decisions covers the longest time period?
- **a)** Short-term scheduling
- **b)** Capacity planning
- **c)** Aggregate planning
- **d)** A master schedule

LO2. A visual aid used in loading and scheduling jobs is a:
- **a)** Gantt chart.
- **b)** planning file.
- **c)** bottleneck.
- **d)** load-schedule matrix.
- **e)** level material chart.

LO3. The assignment method involves adding and subtracting appropriate numbers in the table to find the lowest ______ for each assignment.
- **a)** profit
- **b)** number of steps
- **c)** number of allocations
- **d)** range per row
- **e)** opportunity cost

LO4. The most popular priority rules include:
- **a)** FCFS.
- **b)** EDD.
- **c)** SPT.
- **d)** all of the above.

LO5. The job that should be scheduled last when using Johnson's rule is the job with the:
- **a)** largest total processing time on both machines.
- **b)** smallest total processing time on both machines.
- **c)** longest activity time if it lies with the first machine.
- **d)** longest activity time if it lies with the second machine.
- **e)** shortest activity time if it lies with the second machine.

LO6. What is computerized short-term scheduling that overcomes the disadvantage of rule-based systems by providing the user with graphical interactive computing?
- **a)** LPT
- **b)** FCS
- **c)** CSS
- **d)** FCFS
- **e)** GIC

LO7. Cyclical scheduling is used to schedule:
- **a)** jobs.
- **b)** machines.
- **c)** shipments.
- **d)** employees.

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