increased from 0 units to 80 units of safety stock for the seat assembly using an FOQ of 230 units. The beginning projected on-hand quantity is still 37 units when the safety stock policy is introduced, and cannot fall below 80 units in any future period thereafter. Compare the results in Figure 11.15 to Figure 11.12. The net effect is to move the second planned order release from week 5 to week 4 to avoid dropping below 80 units in week 6.

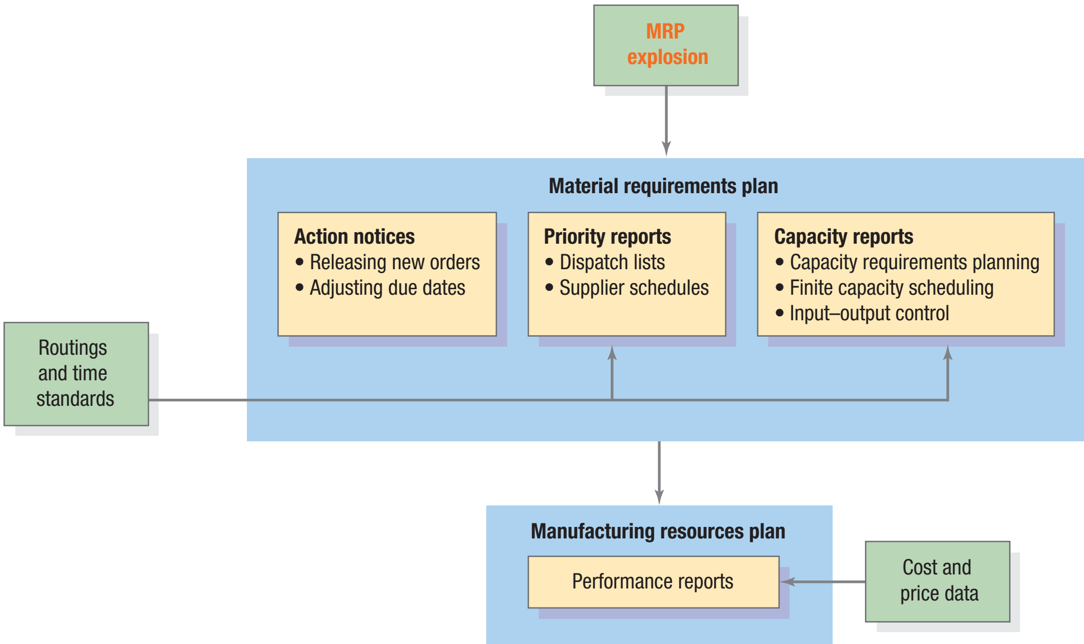
FOQ Rule							**Lot Size:** 230 units **Lead Time:** 2 weeks **Safety Stock:** 80 units		
		Week							
		1	2	3	4	5	6	7	8
Gross requirements		150			120		150	120	
Scheduled receipts		230							
Projected on-hand inventory	37	117	117	117	227	227	307	187	187
Planned receipts					230		230		
Planned order releases			230		230				

▲ **FIGURE 11.15**
Inventory Record for the Seat Subassembly Showing the Application of a Safety Stock

Outputs from MRP

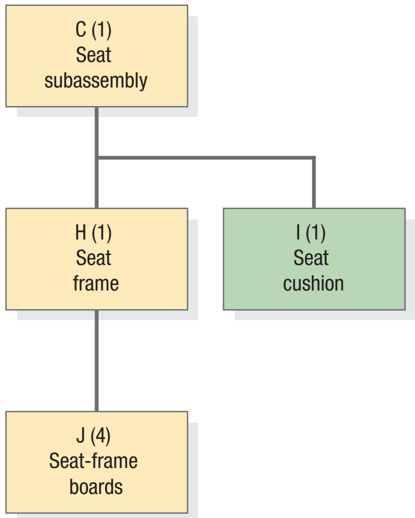
MRP systems provide many reports, schedules, and notices to help planners control dependent demand inventories, as indicated in Figure 11.16. In this section, we discuss the MRP explosion process that generates the material requirements, notices that alert planners to items needing attention, resource requirement reports, and performance reports.

Material Requirements MRP translates, or *explodes*, the MPS and other sources of demand into the requirements needed for all of the subassemblies, components, and raw materials the firm needs to produce parent items. This process generates the material requirements plan for each component item.



◀ **FIGURE 11.16**
MRP Outputs

▼ **FIGURE 11.17**
BOM for the Seat Subassembly



An item's gross requirements are derived from three sources:

1. The MPS for immediate parents that are end items
2. The planned order releases (*not* the gross requirements, scheduled receipts, or planned receipts) for immediate parents below the MPS level
3. Any other requirements not originating in the MPS, such as the demand for replacement parts

Consider the seat subassembly and its inventory record shown in Figure 11.12. The seat subassembly requires a seat cushion and a seat frame, which in turn needs four seat-frame boards. Its BOM is shown in Figure 11.17 (see also Figure 11.10, which shows how the seat subassembly BOM relates to the product as a whole). How many seat cushions should we order from the supplier? How many seat frames should we produce to support the seat subassembly schedule? How many seat-frame boards do we need to make? The answers to these questions depend on the existing inventories of these items and the replenishment orders already in progress. MRP can help answer these questions through the explosion process.

Figure 11.18 shows the MRP records for the seat subassembly and its components. We already showed how to develop the MRP record for the seat subassembly. We now concentrate

Item: Seat subassembly
Lot size: 230 units

Lead time: 2 weeks		Week 1	2	3	4	5	6	7	8
Gross requirements		150			120		150	120	
Scheduled receipts		230							
Projected inventory	37	117	117	117	227	227	77	187	187
Planned receipts					230			230	
Planned order releases			230			230			

Usage quantity: 1

Usage quantity: 1

Item: Seat frames
Lot size: 300 units

Lead time: 2 weeks		Week 1	2	3	4	5	6	7	8
Gross requirements			230			230			
Scheduled receipts			300						
Projected inventory	40	40	110	110	110	180	180	180	180
Planned receipts						300			
Planned order releases				300					

Item: Seat cushion
Lot size: L4L

Lead time: 1 week		Week 1	2	3	4	5	6	7	8
Gross requirements			230			230			
Scheduled receipts									
Projected inventory	0	0	0	0	0	0	0	0	0
Planned receipts			230			230			
Planned order releases		230			230				

Usage quantity: 4

Item: Seat-frame boards
Lot size: 1,500 units

Lead time: 1 week		Week 1	2	3	4	5	6	7	8
Gross requirements				1,200					
Scheduled receipts									
Projected inventory	200	200	200	500	500	500	500	500	500
Planned receipts				1,500					
Planned order releases			1,500						

▲ **FIGURE 11.18**
MRP Explosion of Seat Assembly Components

MyOMLab Animation

on the MRP records of its components. The lot-size rules are an FOQ of 300 units for the seat frame, L4L for the seat cushion, and an FOQ of 1,500 for the seat-frame boards. All three components have a 1-week lead time. The key to the explosion process is to determine the proper timing and size of the gross requirements for each component. After we make those determinations, we can derive the planned order release schedule for each component by using the logic already demonstrated.

In our example, the components have no independent demand for replacement parts. Consequently, in Figure 11.18 the gross requirements of a component come from the planned order releases of its parents. The seat frame and the seat cushion get their gross requirements from the planned order release schedule of the seat subassembly. Both components have gross requirements of 230 units in weeks 2 and 5, the same weeks in which we will be releasing orders to make more seat subassemblies. In week 2, for example, the materials handler for the assembly department will withdraw 230 seat frames and 230 seat cushions from inventory so that the assembly department can produce the seat subassemblies in time to avoid a stockout in week 4. The materials plans for the seat frame and the seat cushion must allow for that.

Using the gross requirements in weeks 2 and 5, we can develop the MRP records for the seat frame and the seat cushion, as shown in Figure 11.18. For a scheduled receipt of 300 seat frames in week 2, an on-hand quantity of 40 units, and a lead time of 1 week, we need to release an order of 300 seat frames in week 4 to cover the assembly schedule for the seat subassembly. The seat cushion has no scheduled receipts and no inventory on hand; consequently, we must place orders for 230 units in weeks 1 and 4, using the L4L logic with a lead time of 1 week.

After determining the replenishment schedule for the seat frame, we can calculate the gross requirements for the seat-frame boards. We plan to begin producing 300 seat frames in week 4. Each frame requires 4 boards, so we need to have $300(4) = 1{,}200$ boards available in week 4. Consequently, the gross requirement for seat-frame boards is 1,200 in week 4. Given no scheduled receipts, 200 boards in stock, a lead time of 1 week, and an FOQ of 1,500 units, we need a planned order release of 1,500 in week 3.

The questions posed earlier can now be answered. We should plan to release the following orders: 300 seat frames in week 4; 230 seat cushions in each of weeks 1 and 4; and 1,500 seat-frame boards in week 3. If MRP plans are updated weekly, only the planned order for week 1 should be released now. Releasing it creates a scheduled receipt of 230 seat cushions that will appear in the updated inventory record. The other orders remain in the planning stage, and even might be revised by the MRP explosion done next week.

In practice, a company can have thousands of dependent demand items with an average of six bills of materials levels. Time horizons often stretch out for 30 or more time periods into the future. Doing a MRP explosion by hand, as shown in Figure 11.18, would be impractical. What is needed is massive data processing, the very thing that computers do best, leaving the decision making to the inventory analyst. The *Material Requirements Planning* Solver of OM Explorer in MyOMLab represents a small example of what is done on a much larger scale by commercial packages. It can compute requirements for up to two end items, and has the ability to develop inventory records up to 18 items deep with little effort, and can easily recompute these requirements if there is any change in planning parameters.

MyOMLab

Action Notices Once computed, inventory records for any item appearing in the BOM can be printed in hard copy or displayed on a computer video screen. Inventory planners use a computer-generated memo called an **action notice** to make decisions about releasing new orders and adjusting the due dates of scheduled receipts. For instance, based on the output in Figure 11.18, an action notice would be issued to bring to the attention of the inventory planner the planned order release of 230 units for seat cushions. Its planned order release is now "mature" for release this week. Unless the planner knows of a problem, the planner would place the order with the supplier. At the same time, the planner would input a transaction that automatically eliminates the planned order release in period 1, removes the planned receipt in period 2, and inserts a scheduled receipt for 230 units in period 2. The planner need not look at the records for seat frames or seat-frame boards, because no action is needed for them.

action notice

A computer-generated memo alerting planners about releasing new orders and adjusting the due dates of scheduled receipts.

Action notices are generated every time the system is updated, typically once per week. The action notice alerts planners to only the items that need their attention, such as those items that have a planned order release in the current period or a scheduled receipt that needs its due date revised. Planners can then view the full records for those items and take the necessary actions. An action notice can simply be a list of part numbers for items that need attention; or it can be the full record for such items, with a note at the bottom identifying the action needed.

Resource Requirements Reports By itself, the MRP system does not recognize capacity limitations when computing planned orders; that is, it may call for a planned order release that exceeds the amount that can be physically produced. An essential role of planners is to monitor the capacity requirements of material requirements plans, adjusting a plan when it cannot be met. Particular attention is paid to bottlenecks. The planner can apply theory of constraints (TOC) principles (see Chapter 5, "Managing Process Constraints") to keep bottleneck operations fed by adjusting some lot sizing rules or occasionally overriding planned order releases. To facilitate this process, various types of capacity reports can be provided. For example, **capacity requirements planning (CRP)** reports project time-phased capacity requirements for workstations. They calculate workload according to the work required to complete the scheduled receipts already in the shop and to complete the planned order releases not yet released. Bottlenecks are those workstations at which the projected loads exceed station capacities.

capacity requirements planning (CRP)

A technique used for projecting time-phased capacity requirements for work stations; its purpose is to match the materials requirements plan with the capacity of key processes.

manufacturing resource planning (MRP II)

A system that ties the basic MRP system to the company's financial system and to other core and supporting processes.

Performance Reports Other types of outputs are also possible, such as priority reports on orders already placed to the shop or with suppliers. Priority reports begin with the due dates assigned to scheduled receipts, which planners keep up to date so that they continue to reflect when receipt is really needed. On a broader scale, the information in an MRP system is useful to functional areas other than operations. MRP evolved into **manufacturing resource planning (MRP II)**, a system that ties the basic MRP system to the company's financial system and to other core and supporting processes. For example, management can project the dollar value of shipments, product costs, overhead allocations, inventories, backlogs, and profits by using the MRP plan along with prices and product and activity costs from the accounting system. Also, information from the MPS, scheduled receipts, and planned orders can be converted into cash flow projections, which are broken down by product families. Similar computations are possible for other performance measures of interest to management. Some firms may, however, forgo the cost of vendor-delivered MRP systems because of the huge budgets and company resources involved in their deployment, and instead create their own MRP system implementations in-house.

MRP and the Environment

Consumer and governmental concern about the deterioration of the natural environment has driven manufacturers to reengineer their processes to become more environmentally friendly. The recycling of base materials is becoming more commonplace, and products are being designed in such a way that they can be remanufactured after their useful lives. Nonetheless, manufacturing processes often produce a number of waste materials that need to be properly disposed of. Wastes come in many forms:

- Effluents, such as carbon monoxide, sulfur dioxide, and hazardous chemicals associated with the processes used to manufacture the product
- Materials, such as metal shavings, oils, and chemicals associated with specific operations
- Packaging materials, such as unusable cardboard and plastics associated with certain products or purchased items
- Scrap associated with unusable products or component defects generated by the manufacturing process

Companies can modify their MRP systems to help them track these wastes and plan for their disposal. The type and amount of waste associated with each item can be entered into its BOM by treating the waste much like you would a component of the item. When the MPS is developed for a product, reports can be generated that project the amount of waste expected during the production process and when it will occur. Although this approach can require that a firm's BOM be modified substantially, the benefits are also substantial. Firms can identify their waste problems in advance to eliminate them in some cases (through process improvement efforts) or plan for their proper disposal in others. It also gives the firm a way to generate any formal documentation required by the government to verify that it has complied with environmental laws and policies. See Chapter 15, "Managing Supply Chain Sustainability," for added discussion of the need for recognizing the environment in supply chain operations.

MRP, Core Processes, and Supply Chain Linkages

Among the four core processes of an organization that link activities within and across firms in a supply chain, the MRP system interacts with all of them either through its inputs or its outputs. It all begins with customer orders, which consist of orders for end items as well as replacement parts. MRP and resource planning typically reside inside the order fulfillment process. The MPS is an integral part of MRP (see Figure 11.1). As shown schematically in Figure 11.19, the MPS drives the feedback between the order fulfillment process and the customer relationship process through confirmation of order receipts and promised due dates. The MPS also provides guidance to the sales group within the customer relationship process with respect to when future orders can be promised, and whether the due dates for existing orders can be adjusted in the time frame requested. The new service and product development process provides an updated BOM to the MRP system, and makes sure that every component and assembly needed for manufacturing of end items is properly recognized.

In a similar vein on the inbound side, orders to external suppliers are based on the planned order releases, which come directly from the output of MRP reports. The power of MRP, however, becomes evident when changes to an existing schedule are needed. These changes can be generated, for example,

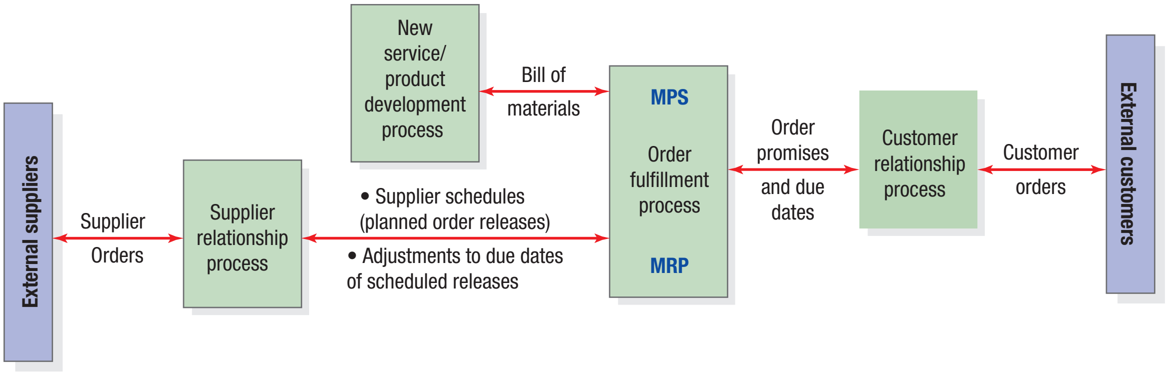


FIGURE 11.19
MRP Related Information Flows in the Supply Chain

by changes to the MPS because a customer wants to change the timing or size of future orders, by some internal failure such as material shortages or unexpected machine downtime, or by supplier failure. In a supply chain, schedule changes have implications for customers as well as suppliers. Some firms, in partnership with their suppliers, have MRP systems that can actually "see" into their suppliers' inventory to determine if a particular item is in stock or, if not, when it can be expected. This is an advantage when contemplating a change to the original schedule of order releases. While systems such as this are powerful tools for making changes, care must be taken to avoid unnecessary fluctuations in the timing and size of planned order releases because of the choice of lot sizing policy. As we have seen, lot sizing rules such as POQ or L4L are susceptible to changes in requirements, and using them indiscriminately can cause instability in replenishment orders. In turn, this instability can be transmitted up the supply chain if the firm's MRP system is electronically linked to the production planning and control systems of its immediate suppliers.

Execution of MRP-based plans using the information flows between core processes as shown in Figure 11.19 properly link a firm with its upstream and downstream supply chain partners. Valid customer and supplier priorities would not be effectively recognized without such an MRP-based framework, which in many firms is actually implemented through an ERP system that we discuss next in this chapter.

enterprise process

A companywide process that cuts across functional areas, business units, geographical regions, and product lines.

enterprise resource planning (ERP) systems

Large, integrated information systems that support many enterprise processes and data storage needs.

Enterprise Resource Planning

An **enterprise process** is a companywide process that cuts across functional areas, business units, geographic regions, product lines, suppliers, and customers. **Enterprise resource planning (ERP) systems** are large, integrated information systems that support many enterprise processes and data storage needs. By integrating the firm's functional areas, ERP systems allow an organization to view its operations as a whole rather than having to try to put together the different information pieces produced by its various functions and divisions. Today, ERP systems are being used by traditional brick-and-mortar organizations such as manufacturers, restaurants, hospitals, and hotels, as well as by Internet companies that rely extensively on Web connectivity to link their customers and suppliers.


Pavel Losevsky/Fotolia

Golden Road, a small brewery making craft beer is using a cloud-based ERP system to compete in Los Angeles—without breaking the bank.

How ERP Systems Are Designed

ERP revolves around a single comprehensive database that can be made available across the entire organization (or enterprise). Security restricts system usage to allow personnel access to certain areas of the system. Having a single database for all of the firm's information makes it much easier for managers to monitor all of the company's products at all locations and at all times. The database collects data and feeds them into the various modular applications (or suites) of the software system. As new information is entered as a *transaction* in one application, related information is automatically updated in the other applications, including the firm's

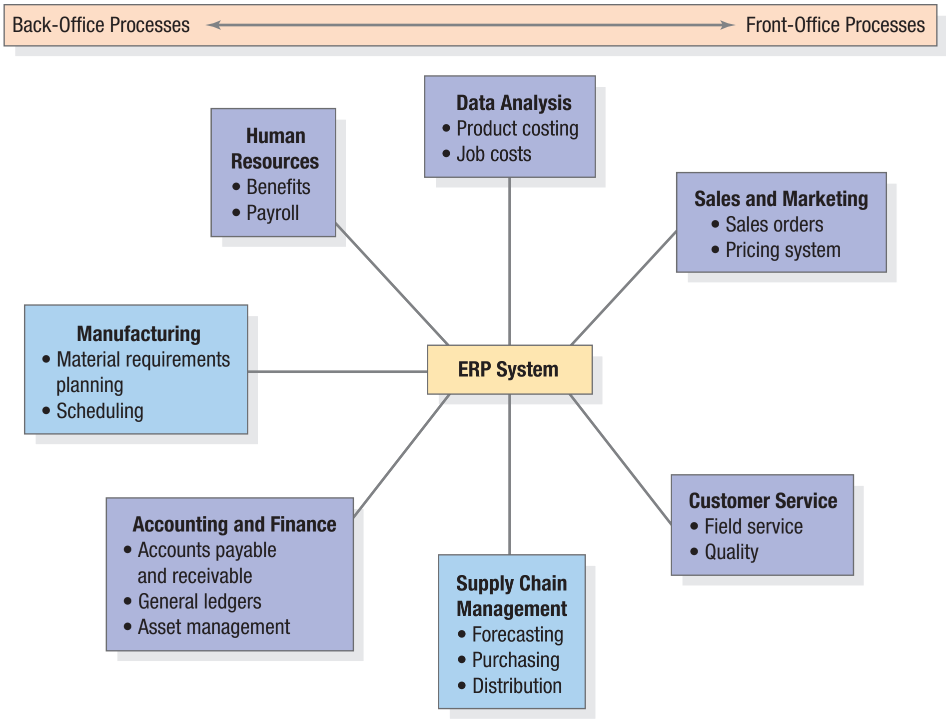


FIGURE 11.20
ERP Application Modules
Source: Based on *Enterprise Resource Planning (ERP)* by Scalle and Cotteleer, Harvard Business School Press. Boston, MA, 1999, No. 9-699-020.

financial and accounting databases, its human resource and payroll databases, sales, supplier and customer databases, and so forth. In this way, the ERP system streamlines the data flows throughout the organization and supply chain and provides employees with direct access to a wealth of real-time operating information scattered across different functions in the organization. Figure 11.20 shows some of the typical applications with a few subprocesses nested within each one. Some of the applications are for back-office operations such as manufacturing and payroll, while others are for front-office operations such as customer service. The Manufacturing and Supply Chain Management modules in Figure 11.20 specifically deal with resource planning. In fact for many firms, MRP II ultimately evolved into ERP.

Amazon.com is one company that uses an ERP system. The supply chain application of Amazon's system is particularly important because it allows Amazon.com to link customer orders to warehouse shipments and, ultimately, to supplier replenishment orders. Other applications are more important in other businesses. For example, universities put particular emphasis on the human resources and accounting and finance applications, and manufacturers have an interest in almost every application suite. Not all applications in Figure 11.20 need to be integrated into an ERP system, but those left out will not share their information with the ERP system. Sometimes, however, ERP systems are designed to interface with a firm's existing, older information systems (called "legacy systems").

Designing an ERP system requires that a company carefully analyze its major processes so that appropriate decisions about the coordination of legacy systems and new software can be made. Sometimes, a company's processes that involve redundancies and convoluted information flows must be completely reengineered before the firm can enjoy the benefits of an integrated information system. However, a recent study showed that companies reap the greatest rewards when they keep their ERP implementations simple, work with a small number of software vendors, and use standardized systems rather than customizing them extensively. Firms can otherwise end up spending excessive amounts of money on ERP systems that are complex to use and costly to manage.

Most ERP systems today use a graphical user interface, although the older, keyboard-driven, text-based systems are still popular because of their dependability and technical simplicity. Users navigate through various screens and menus. Training, such as during ERP implementation, focuses on these screens and how users can utilize them to get their jobs done. The biggest suppliers of these off-the-shelf commercial ERP packages are SAP AG, followed by Oracle Corporation. Managerial Practice 11.1 illustrates how the implementation of an ERP system by SAP-benefited Dow Corning.

MANAGERIAL PRACTICE 11.1 ERP Implementation by SAP at DOW Corning

Dow Corning, created as a joint venture between Corning Incorporated and the Dow Chemical Company in 1943, is a global leader that offers over 7,000 innovative products and services using silicon-based technology in diverse industries such as electronics, aviation and aerospace, textile, automotive, and health care, among others. As an example, Dow Corning's Electrical Insulating Compounds are used for creating moisture proof seals for aircraft, automotive, and marine ignition systems. With 11,000 employees, 25,000 customers, and 62 offices and manufacturing locations worldwide, its annual revenues of $5.71 billion generated a net income of $376 million in 2013. More than half its sales are outside the United States.

To integrate different business functions and enhance resource planning across the entire firm and its supply chain, Dow Corning turned to SAP, a leading provider of ERP software solutions since 1973. As the third largest software provider firm by revenue, SAP operates a global network of 115 subsidiaries and research and development (R&D) facilities in the United States, Asia, Europe, and Latin America. SAP delivers role-based access to crucial data, applications, and analytical tools, and has a suite of applications for business processes (like financial management, customer relationship management, human capital management, and supply chain management), business analytics, and technology.

Dow installed the SAP R/3 and my SAP Supply Chain Management solution, with SAP Advanced Planner and Optimizer (APO) at its core. Prior to the ERP implementation, limited transparency and redundancy within the existing legacy systems made it difficult to access and analyze data needed for effective resource planning, and also hampered decision making and responsiveness. A sequenced implementation of the SAP modules facilitated the linking of key processes from order generation to production planning to warehousing to delivery and final billing. The SAP APO solution enabled the SCOR model of plan, source, make, and deliver (see Chapter 14, “Integrating the Supply Chain”), which allowed the linkage of shop floor processes and manufacturing operations with the rest of the business. With a transparent view of orders, materials, equipment, product quality, and cost information, Dow Corning can now coordinate plants and processes with greater ease and better match production to market requirements on a global scale. Employee productivity and satisfaction are also up, due mostly to faster response times and accurate on-time deliveries.

Stefan Kiefer/imagebroker/Alamy

Headquarters of the software company SAP AG in Walldorf, Baden-Wuerttemberg, Germany, Europe

Sources: End to End Supply Chain Management at Dow Corning, **http://www.sap.com/usa/solutions/business-suite/erp/operations/pdf/CS_Dow_Corning.pdf** (May 29, 2011); Dow Corning, Optimizing Operational Performance to Sharpen Competitive Advantage, **http://www12.sap.com/index.epx#/solutions/index.epx; http://www.sap.com** (May 29, 2011); **http://www.dowcorning.com/content/about/aboutmedia/fastfacts.asp** (August 12, 2014); **http://en.wikipedia.org/wiki/SAP_SE** (August 16, 2014).

Resource Planning for Service Providers

We have seen how manufacturing companies can disaggregate an MPS of finished products, which in turn must be translated into the needs for resources, such as staff, equipment, components, and financial assets. The driver for these resource requirements is a material requirements plan. Service providers, of course, must plan their resources just as manufacturers do. However, unlike finished goods, services cannot be inventoried. They must be provided on demand. In terms of resource planning then, service organizations must focus on maintaining the *capacity* to serve their customers. In this section, we will discuss how service providers use the concept of dependent demand and a bill of resources in managing capacity.

Dependent Demand for Services

When we discussed planning and control systems for manufacturers earlier in this chapter, we introduced the concept of *dependent demand*, which is demand for an item that is a function of the production plans for some other item the company produces. For service resource planning, it is useful to define the concept of dependent demand to include demands for resources that are driven by forecasts of customer requests for services or by plans for various activities in support of the services the company provides. Here are some other examples of dependent demands for service providers.

Restaurants Every time you order from the menu at a restaurant, you initiate the restaurant’s need for certain types of goods (uncooked food items, plates, and napkins), staff (chef, servers, and dishwashers), and equipment (stoves, ovens, and cooking utensils). Using a forecast of the demand for each type of meal, the manager of the restaurant can estimate the need for these resources. Many restaurants, for example, feature “specials” on certain days, say, fish on Fridays or prime rib on Saturdays. Specials improve the accuracy of the forecasts managers need to make for different types of meals (and the food products that are required to make them) and typically signal the need for above-average staffing levels. How much of these resources will be needed, however, depends on the number of meals the restaurant ultimately expects to serve. As such, these items—food products and staff members—are dependent demands.

Airlines Whenever an airline schedules a flight, certain supporting goods are needed (beverages, snacks, and fuel), labor (pilots, flight attendants, and airport services), and equipment (a plane and airport gate). The number of flights and passengers the airline forecasts it will serve determines


ochen Tack/PhotoLibrary

Doctors and nurses in operation room during surgery

the amount of these resources needed. Just like a manufacturer, the airline can translate its master schedule of flights into resource requirements.

Hospitals With the exception of the emergency room services, hospitals can use their admission appointments to create a master schedule. The master schedule can be exploded to determine the resources the hospital will need during a certain period. For example, when you schedule a surgical procedure, you generate a need for facilitating goods such as medicines, surgical gowns, linens, staff (a surgeon, nurses, and an anesthesiologist), and equipment (an operating room, surgical tools, and a recovery bed). As they build their master schedules, hospitals must ensure that certain equipment and personnel do not become overcommitted—that capacity is maintained, in other words. For example, an appointment for a key operation might have to be scheduled in advance at a time a surgeon is available to do it, even though the hospital's other resources—operating room, nurses, and so forth—might be currently be available.

Hotels A traveler who makes a reservation at a hotel generates demand for facilitating goods (soap and towels), staff (front desk, housekeeping, and concierge), and equipment (fax, television, and exercise bicycle). To determine its dependent resource needs, a hotel adds the number of reservations already booked to the number of "walk-in" customers it forecasts it will have. This figure is used to create the hotel's master schedule. One resource a hotel cannot easily adjust, however, is the number of rooms it has. If the hotel is overbooked, for instance, it cannot simply add more rooms. If it has too few guests, it cannot "downsize" its number of rooms. Given the high capital costs needed for this resource, hotels try to maintain as high a utilization rate as possible by offering group rates or special promotions at certain times of the year. In other words, they try to drive up dependent demand for this particular resource.

Bill of Resources

bill of resources (BOR)

A record of a service firm's parent–component relationships and all of the materials, equipment time, staff, and other resources associated with them, including usage quantities.

The service analogy to the bill of materials in a manufacturing company is the **bill of resources (BOR)**, which is a record of a service firm's parent–component relationships and all of the materials, equipment time, staff, and other resources associated with them, including usage quantities. Once the service firm has completed its master schedule, the BOR can be used to determine what resources the firm will need, how much of them it will need, and when. A BOR for a service provider can be as complex as a BOM for a manufacturer.

Consider a comprehensive regional hospital that among many other procedures also performs aneurysm treatment at its state-of-the-art facility. As shown in Figure 11.21(a), the BOR for treatment of an aneurysm has seven levels, starting at the top (end item): (1) discharge, (2) intermediate care, (3) postoperative care (step down), (4) postoperative care (intensive), (5) surgery, (6) preoperative care (angiogram), and (7) preoperative care (testing). Each level of the BOR has a set of material and resource requirements and an associated lead time. For example, at level 6, shown in Figure 11.21(b), the patient needs 6 hours of nurses' time, 1 hour of the primary MD's time, 1 hour of the respiratory therapist's time, 24 hours of bed time, three different lab tests, one meal, and 10 different medicines from the pharmacy. The lead time for this level is 1 day. As shown in Figure 11.21, the cumulative lead time, or the patient stay time at the hospital, across all seven levels for the entire duration of the aneurysm treatment is 10 days.

The hospital is interested in understanding how much of each critical resource of nurses, beds, and lab tests will be needed if the projected patient departures from the aneurysm treatment process over the next 15 days are as shown in Table 11.1. The first 10 days of the projected departures represent actual patients who have started the process (booked orders), while the last 5 days represent patients who were either prescheduled ahead of time to depart after the aneurysm treatment, or patients who based on historical records were forecasted to depart after receiving the aneurysm treatment. In effect, Table 11.1 is an MPS for the aneurism process based on the activity at the discharge level. In addition, resources required for treating each aneurysm patient at each level of the BOR are shown in Table 11.2.

To use the information in Table 11.2 to calculate the daily resource requirements for treating aneurysm patients (similar to the gross requirements in a MRP record), we begin by calculating the number of patients that will be at each level (or stage) of treatment each day. As shown in Figure 11.22, the aneurism patient departures become the master schedule for level 1. These departures drive the need for resources at each level of the process. Resource calculations are worked backwards from level 1, while

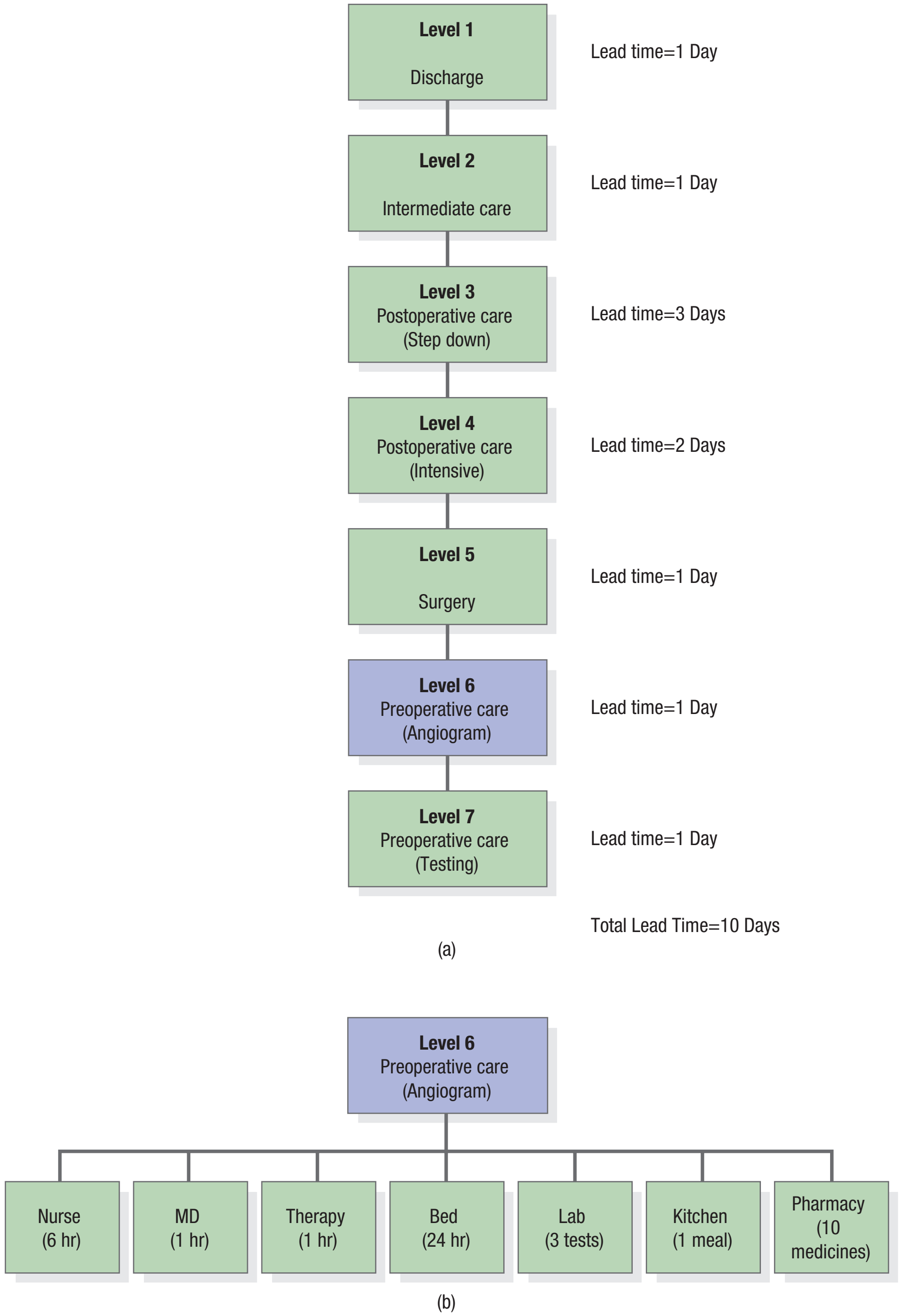


FIGURE 11.21 BOR for Treating an Aneurysm

TABLE 11.1 PROJECTED PATIENT DEPARTURES FROM ANEURYSM TREATMENT

Day of the Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Aneurysm Patients	1	2	1	3	2	3	0	1	2	1	2	2	2	2	2

explicitly recognizing lead times. For example, follow the patient who is scheduled to depart on day 10 (**blue**). That patient would be on level 1 on day 10, level 2 on day 9, spend three days on level 3 and two days on level 4, spend one day each on levels 5 and 6, and be at level 7 on day 1. Following the same process for each patient in the master schedule enables us to determine the patients residing at each level on a given day. Consider level 4, which has a lead time of two days. We must accumulate the patients that are spending multiple days at this level, always remembering to offset the lead times. For example, the three patients at level 4 on day 5 represent the patient scheduled to depart on day 10 and the two patients scheduled to depart on day 11 from the hospital.

TABLE 11.2 RESOURCE REQUIREMENTS FOR TREATING AN ANEURYSM AT EACH LEVEL OF BOR

Resources Required for Each Aneurysm Patient	Nurse Hours Required Per Patient Per Day	Beds Required Per Patient Per Day	Lab Tests Required Per Patient Per Day
Level 1	0	0	0
Level 2	6	0	0
Level 3	16	1	4
Level 4	12	1	6
Level 5	22	1	2
Level 6	6	1	3
Level 7	1	0	0

FIGURE 11.22 Number of Patients at Each Level of the Aneurysm Treatment

Notes: Aneurysm patient departures are actual patients for days 1-10 and forecasted departures for days 11-15. Transfers to next level or departure from hospital are at the end of the day. The rows represent numbers of patients in process for each level, accounting for Lead Times (LT) shown for each level. The top row of each level shows the number of patients who will advance to the next level at the end of the day.

Day of the Month		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Aneurysm Patient Departures		1	2	1	3	2	3	0	1	2	1	2	2	2	2	2
Number of Patients at Level 1 (LT = 1 Day)		1	2	1	3	2	3	0	1	2	1	2	2	2	2	2
Number of Patients at Level 2 (LT = 1 Day)		2	1	3	2	3	0	1	2	1	2	2	2	2	2	
Number of Patients at Level 3 (LT = 3 Days)	Advancing to Level 2	1	3	2	3	0	1	2	1	2	2	2	2	2		
	In Progress Second Day	3	2	3	0	1	2	1	2	2	2	2	2			
	In Progress First Day	2	3	0	1	2	1	2	2	2	2	2	_	_		
	Total	6	8	5	4	3	4	5	5	6	6	6	4	2		
Number of Patients at Level 4 (LT = 2 Days)	Advancing to Level 3	3	0	1	2	1	2	2	2	2	2					
	In Progress First Day	0	1	2	1	2	2	2	2	2	_					
	Total	3	1	3	3	3	4	4	4	4	2					
Number of Patients at Level 5 (LT = 1 Day)		1	2	1	2	2	2	2	2							
Number of Patients at Level 6 (LT = 1 Day)		2	1	2	2	2	2	2								
Number of Patients at Level 7 (LT = 1 Day)		1	2	2	2	2	2									

Once we know how many patients will need each level of treatment on each day, we can multiply this demand by the amount of each resource required to treat them. For example, on day 5, the projected number of lab tests required is calculated by multiplying the patients at each level on day 5 by the number of lab tests each level requires per day. Starting at level 1, which requires 0 tests and has two patients, a total of 40 tests will be required as shown below.

$$\text{Total Number of Lab Tests Projected for Day 5} = [0(2) + 0(3) + 4(3) + 6(3) + 2(2) + 3(2) + 0(2)] = \mathbf{40}$$

Note in Figure 11.22 that due to the lead times involved, there is diminishing visibility into future resource requirements as we go down the BOR. This problem can be remedied by projecting the master schedule farther into the future.

Table 11.3 shows how much of each critical resource is required in total to treat aneurysm patients for the 15-day master schedule. While the busiest day for the nursing staff will be on day 2, the busiest day for the lab will be on day 7 when 54 tests will be requested. It is also important to note that 13 beds will serve the clinic for aneurysm patients throughout this 15-day planning horizon. Notice that for all the patients departing before day 10, nursing hours, beds, and lab tests resources that were consumed in the past (before day 1) at lower levels in the BOR (levels 5, 6, 7 for instance) are not reflected in Table 11.3. Any delays in patient treatment prior to day 1 will have been reflected in adjustments to the

TABLE 11.3 TOTAL RESOURCE REQUIREMENTS FOR TREATING ANEURYSM PATIENTS

Day of the Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Nursing Hours Required	179	198	170	170	160	170	190	184	150	132	108	76	44	12	0
Beds Required	12	12	11	11	10	12	13	11	10	8	6	4	2	0	0
Lab Tests Required	50	45	46	44	**40**	50	54	48	48	36	24	16	8	0	0

master schedule of departures. Consequently, what we see in Table 11.3 are the resources needed from day 1 to day 15 for the current master schedule.

Just like projecting the total resource requirements for treating aneurysms, a master schedule of patient admissions and the BORs for each illness can enable the hospital to manage its critical resources. Reports analogous to the MRP II reports we discussed earlier in the chapter can be generated for the people who manage the various functional areas of the hospital.

One resource every service provider needs, however, is cash. Service organizations have to forecast the number of customers they expect to serve so that they have enough cash on hand to purchase materials that support the services—labor and other products. Purchasing these items increases the firm's accounts payable. As services are actually completed for customers, the firm's accounts receivable increases. The firm's master schedule and its accounts receivable and payable help a company predict the amount and timing of its cash flows.

LEARNING GOALS IN REVIEW

Learning Goal	Guidelines for Review	MyOMLab Resources
1 Explain how the concept of dependent demand in material requirements planning is fundamental to resource planning.	See the sub-section on "Dependent Demand," pp. 459–460, which shows how continuous independent demand can lead to lumpy requirements for dependent demand. Then, a separate system, called Material Requirements Planning (MRP), is needed to manage dependent demand situations.	**Video:** Gate Turnaround at Southwest Airlines
2 Describe a master production schedule (MPS) and compute available-to-promise quantities.	The section "Master Production Scheduling," pp. 460–464, shows you how firms break down a production plan into more detailed schedules. Understand the key relationships between Figures 11.3, 11.4, and 11.5.	**OM Explorer Solver:** Master Production Scheduling **OM Explorer Tutor:** 11.1: Master Production Scheduling
3 Apply the logic of an MRP explosion to identify production and purchase orders needed for dependent demand items.	Using Figure 11.11, p. 426, understand how an inventory record is created for a given lot size rule. The subsection on "Planning Factors," pp. 468–471, shows you how choice of different managerial policies affect material plans. Finally, focus on understanding the MRP explosion process as illustrated in Figure 11.17 on p. 471 and Solved Problem 3 on p. 484.	**Active Model Exercise:** 11.1: Material Requirements Planning **OM Explorer Solver:** Material Requirements Planning Single-Item MRP **OM Explorer Tutor:** 11.2: FOQ, POQ, and L4L Rules
4 Explain how enterprise resource planning (ERP) systems can foster better resource planning.	Review the section on "Enterprise Resource Planning," pp. 475–477. Pay attention to Figure 11.20 to understand how different application modules come together to create functionality and value in the ERP systems.	
5 Apply resource planning principles to the provision of services and distribution inventories.	The section, "Resource Planning for Service Providers," pp. 477–481, and Solved Problem 4, pp. 486–487 illustrate how the Bill of Resources can be used to plan dependent demand for services in settings such as the restaurants, airlines, hospitals, and hotels.	

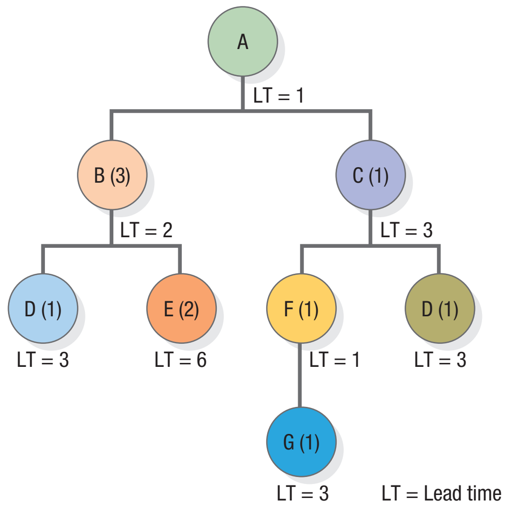
Key Terms

Solved Problem 1

Refer to the bill of materials for product A shown in Figure 11.23.

If there is no existing inventory and no scheduled receipts, how many units of items G, E, and D must be purchased to produce five units of end item A?

FIGURE 11.23 ▶
BOM for Product A



SOLUTION

Five units of item G, 30 units of item E, and 20 units of item D must be purchased to make five units of A. The usage quantities shown in Figure 11.23 indicate that two units of E are needed to make one unit of B and that three units of B are needed to make one unit of A; therefore, five units of A require 30 units of E ($2 \times 3 \times 5 = 30$). One unit of D is consumed to make one unit of B, and three units of B per unit of A result in 15 units of D ($1 \times 3 \times 5 = 15$); one unit of D in each unit of C and one unit of C per unit of A result in another five units of D ($1 \times 1 \times 5 = 5$). The total requirements to make five units of A are 20 units of D ($15 + 5$). The calculation of requirements for G is simply $1 \times 1 \times 1 \times 5 = 5$ units.

Solved Problem 2

The order policy is to produce end item A in lots of 50 units. Using the data shown in Figure 11.24 and the FOQ lot-sizing rule, complete the projected on-hand inventory and MPS quantity rows. Then, complete the MPS start row by offsetting the MPS quantities for the final assembly lead time. Compute the available-to-promise inventory for item A. Finally, assess the following customer requests for new orders. Assume that these orders arrive consecutively and their affect on ATP is cumulative. Which of these orders can be satisfied without altering the MPS Start quantities?

Item: A										**Order Policy:** 50 units **Lead Time:** 1 week
Quantity on Hand: 5	**Week**									
	1	2	3	4	5	6	7	8	9	10
Forecast	20	10	40	10			30	20	40	20
Customer orders (booked)	30	20	5	8		2				
Projected on-hand inventory	25									
MPS quantity	50									
MPS start										
Available-to-promise (ATP) inventory										

FIGURE 11.24
MPS Record for End Item A

a. Customer A requests 30 units in week 1.
b. Customer B requests 30 units in week 4.
c. Customer C requests 10 units in week 3.
d. Customer D requests 50 units in week 5.

SOLUTION

The projected on-hand inventory for the second week is

$$\begin{pmatrix}\text{Projected on-hand}\\\text{inventory at end}\\\text{of week 2}\end{pmatrix} = \begin{pmatrix}\text{On-hand}\\\text{inventory in}\\\text{week 1}\end{pmatrix} + \begin{pmatrix}\text{MPS quantity}\\\text{due in week 2}\end{pmatrix} - \begin{pmatrix}\text{Requirements}\\\text{in week 2}\end{pmatrix}$$
$$= 25 + 0 - 20 = 5 \text{ units}$$

where requirements are the larger of the forecast or actual customer orders booked for shipment during this period. No MPS quantity is required.

Without an MPS quantity in the third period, a shortage of item A will occur: $5 + 0 - 40 = -35$. Therefore, an MPS quantity equal to the lot size of 50 must be scheduled for completion in the third period. Then, the projected on-hand inventory for the third week will be $5 + 50 - 40 = 15$.

Figure 11.25 shows the projected on-hand inventories and MPS quantities that would result from completing the MPS calculations. The MPS start row is completed by simply shifting a copy of the MPS quantity row to the left by one column to account for the 1-week final assembly lead time. Also shown are the available-to-promise quantities. In week 1, the ATP is

$$\begin{pmatrix}\text{Available-to-}\\\text{Promise in}\\\text{week 1}\end{pmatrix} = \begin{pmatrix}\text{On-hand}\\\text{quantity in}\\\text{week 1}\end{pmatrix} + \begin{pmatrix}\text{MPS quantity}\\\text{in week 1}\end{pmatrix} - \begin{pmatrix}\text{Orderes booked up}\\\text{to week 3 when the}\\\text{next MPS arrives}\end{pmatrix}$$
$$= 5 + 50 - (30 + 20) = 5 \text{ units}$$

The ATP for the MPS quantity in week 3 is

$$\begin{pmatrix}\text{Available-to-}\\\text{Promise in}\\\text{week 3}\end{pmatrix} = \begin{pmatrix}\text{MPS quantity}\\\text{in week 3}\end{pmatrix} - \begin{pmatrix}\text{Orderes booked up}\\\text{to week 7 when the}\\\text{next MPS arrives}\end{pmatrix}$$
$$= 50 - (5 + 8 + 0 + 2) = 35 \text{ units}$$

Lot Size: 50 units
Lead Time: 1 week

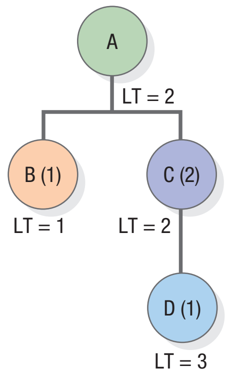
Quantity on Hand: 5	Week 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Forecast	20	10	40	10			30	20	40	20					
Customer orders (booked)	30	20	5	8		2									
Projected on-hand inventory	25	5	15	5	5	3	23	3	13	43					
MPS quantity	50		50				50		50	50					
MPS start		50				50		50	50						
Available-to-promise (ATP) inventory	5		35				50		50	50					

▲ **FIGURE 11.25**
Completed MPS Record for End Item A

The other ATPs equal their respective MPS quantities because no orders are booked for those weeks. As for the new orders, Customer A's request for 30 units in week 1 cannot be accommodated; the earliest it can be shipped is week 3 because the ATP for week 1 is insufficient. Assuming that Customer A's order is rejected, Customer B's request may be satisfied. The ATP for week 1 will stay at five units and the ATP for week 3 will be reduced to five units. This acceptance allows the firm the flexibility to immediately satisfy an order for five units or less, if one comes in. When the MPS is updated next, the customer orders booked for week 4 will be increased to 38 to reflect the new order's shipping date. Customer C's order for 10 units in week 3 is likewise accepted. The ATP for weeks 1 and 3 will be reduced to 0, and when the MPS is updated, the customer orders booked for week 3 will be increased to 15. Finally, Customer D's order for 50 units in week 5 cannot be satisfied without changing the MPS.

Solved Problem 3

MyOMLab Video



▲ **FIGURE 11.26**
BOM for Product A

MyOMLab
Active Model 11.1 in MyOMLab provides additional insight on lot sizing decisions for this problem.

The MPS start quantities for product A calls for the assembly department to begin final assembly according to the following schedule: 100 units in week 2; 200 units in week 4; 120 units in week 6; 180 units in week 7; and 60 units in week 8. Develop a material requirements plan for the next 8 weeks for items B, C, and D. The BOM for A is shown in Figure 11.26, and data from the inventory records are shown in Table 11.4.

SOLUTION

We begin with items B and C and develop their inventory records, as shown in Figure 11.27. The MPS for product A must be multiplied by 2 to derive the gross requirements for item C because of the usage quantity. Once the planned order releases for item C are found, the gross requirements for item D can be calculated.

TABLE 11.4 | INVENTORY RECORD DATA

	ITEM		
Data Category	**B**	**C**	**D**
Lot-sizing rule	POQ ($P = 3$)	L4L	$FOQ = 500$ units
Lead time (LT)	1 week	2 weeks	3 weeks
Scheduled receipts	None	200 (week 1)	None
Beginning (on-hand) inventory	20	0	425

FIGURE 11.27 Inventory Records for Items B, C, and D

Item: B **Description:** **Lot Size:** POQ (P = 3) **Lead Time:** 1 week

		Week									
		1	2	3	4	5	6	7	8	9	10
Gross requirements			100		200		120	180	60		
Scheduled receipts											
Projected on-hand inventory	20	20	200	200	0	0	240	60	0	0	0
Planned receipts			280				360				
Planned order releases		280				360					

Item: C **Description:** **Lot Size:** L4L **Lead Time:** 2 weeks

		Week									
		1	2	3	4	5	6	7	8	9	10
Gross requirements			200		400		240	360	120		
Scheduled receipts		200									
Projected on-hand inventory	0	200	0	0	0	0	0	0	0	0	0
Planned receipts					400		240	360	120		
Planned order releases			400		240	360	120				

Item: D **Description:** **Lot Size:** FOQ = 500 units **Lead Time:** 3 weeks

		Week									
		1	2	3	4	5	6	7	8	9	10
Gross requirements			400		240	360	120				
Scheduled receipts											
Projected on-hand inventory	425	425	25	25	285	425	305	305	305	305	305
Planned receipts					500	500					
Planned order releases		500	500								

Solved Problem 4

The Pet Training Academy offers a 5-day training program for troubled dogs. As seen in Table 11.5, the training process requires 5 days, beginning with the dog's arrival at 8 A.M. on day one, and departure after a shampoo and trim, at 5 P.M. on day five.

TABLE 11.5 | **LEAD TIME DATA FOR THE PET TRAINING ACADEMY**

Pet Training Academy Process	Lead Time in Days
Level 1: Departure Day	1
Level 2: 3rd Day	1
Level 3: 2nd Day	2
Level 4: Arrival Day	1
Total	5

To adequately train a dog, the Academy requires Training Coaches, Dog Dietitians, Care Assistants, and Boarding Kennels where the dogs rest. The time required per dog by each employee and resource classification by process level is provided in Table 11.6.

TABLE 11.6 | **RESOURCE REQUIREMENTS FOR TRAINING DOGS AT THE PET TRAINING ACADEMY**

Pet Training Academy Process Resources Required	Training Coach (Hours Per Dog)	Dog Dietitian (Hours Per Dog)	Care Assistant (Hours Per Dog)	Boarding Kennel (Hours Per Dog)
Level 1: Departure Day	2	1	1	12
Level 2: 3rd Day	3	1	2	24
Level 3: 2nd Day	3	1	2	24
Level 4: Arrival Day	2	1	1	12

The master schedule for the trained dogs is shown below, noting that departures for trained dogs are actual departures for days 1–5 and forecasted departures for days 6–12.

Day of the Month	1	2	3	4	5	6	7	8	9	10	11	12
Master Schedule of Trained Dogs	5	2	2	8	3	0	1	8	4	3	6	0

a. Use the above information to calculate the daily resource requirements in hours for employees in each category, and the hours of boarding room needed to train the dogs.

b. Assuming that each boarding kennel is available for 24 hours in a day, how many kennels will be required each day?

c. Assuming that each employee is able to work only eight hours per day, how many people in each employee category will be required each day?

SOLUTION

a. Figure 11.28 shows the number of dogs at each level during their stay at the Pet Training Academy. The top row of each level shows the number of dogs who will advance to the next level at the end of the day. For example, the three dogs scheduled to depart on day 5 (**blue**) would be at level 1 on day 5, at level 2 on day 4, at level 3 on days 3 and 2, and at level 4 on day 1 right after their arrival at the Pet Training Academy.

The daily resource requirements for each resource required to train the departing dogs are shown in Table 11.7. For example, on day 2, the projected number of hours required for Care Assistant (CA) is calculated by multiplying the number of dogs at each level on day 2 by the number of CA hours each level requires per day. Starting at level 1, which requires 1 hour and has two dogs, a total of 28 hours will be required as shown below.

Total Number of CA Hours Projected for Day 2 $= [1(2) + 2(2) + 2(11) + 1(0)] =$ **28 hours**

Day of the Month		1	2	3	4	5	6	7	8	9	10	11	12
Trained Dog Departures		5	2	2	8	3	0	1	8	4	3	6	0
Number of Dogs at Level 1 (LT = 1 Day)		5	2	2	8	3	0	1	8	4	3	6	0
Number of Dogs at Level 2 (LT = 1 Day)		2	2	8	3	0	1	8	4	3	6	0	
Number of Dogs at Level 3 (LT = 2 Days)	Advancing to Level 2	2	8	3	0	1	8	4	3	6	0		
	In Progress First Day	8	3	0	1	8	4	3	6	0	_		
	Total	**10**	**11**	**3**	**1**	**9**	**12**	**7**	**9**	**6**	**0**		
Number of Dogs at Level 4 (LT = 1 Day)		3	0	1	8	4	3	6	0				

FIGURE 11.28
Number of Dogs at Each Level

TABLE 11.7 TOTAL RESOURCE REQUIREMENTS FOR TRAINING DOGS

Day of the Month	1	2	3	4	5	6	7	8	9	10	11	12
Training Coach hours required	52	43	39	44	41	45	59	55	35	24	12	0
Dog Dietitian hours required	20	15	14	20	16	16	22	21	13	9	6	0
Care Assistant hours required	32	**28**	25	24	25	29	37	34	22	15	6	0
Boarding Kennels hours required	384	336	300	288	300	348	444	408	264	180	72	0
Number of Boarding Kennels required	16	14	13	12	13	15	19	17	11	8	3	0

b. The number of boarding kennels required per day (note that all fractional kennels are rounded to the next higher integer) are obtained by dividing the total numbers of hours needed for boarding kennels by 24, and are shown in the last row in Table 11.7.

c. The number of people required per day in each employee category are obtained by dividing the resource requirements in Table 11.7 by working hours in each day (8), and are shown in Table 11.8. Note that all fractional employees are rounded to the next higher integer.

TABLE 11.8 NUMBER OF EMPLOYEES REQUIRED PER DAY FOR TRAINING DOGS

Number of Employees Required per Day	1	2	3	4	5	6	7	8	9	10	11	12
Training Coaches	7	6	5	6	6	6	8	7	5	3	2	0
Dog Dietitians	3	2	2	3	2	2	3	3	2	2	1	0
Care Assistants	4	4	4	3	4	4	5	5	3	2	1	0

Discussion Questions

1. Form a group in which each member represents a different functional area of a firm. Provide a priority list of the information that could be generated from an MPS, from the most important to the least important, for each functional area. Rationalize the differences in the lists.
2. Consider a company like Emirates, which acquires new airplanes from Airbus or Boeing. Identify dependent demands for both goods and services associated with these acquisitions. Using examples, of both goods and services, discuss the similarities and differences between the two.
3. Consider companies like Amazon.com and Dow Corning, who have successfully utilized ERP systems in their company operations. Explain the design of an ERP system. How can such an integrated information system benefit a company?
4. Consider a service provider that is in the delivery business, such as UPS or FedEx. How can the principles of MRP and BOR be useful to such a company?

Problems

The OM Explorer and POM for Windows software is available to all students using the 11th edition of this textbook. Go to **http://www.pearsonglobaleditions.com/krajewski** website to download these computer packages. If you purchased MyOMLab, you also have access to Active Models software and significant help in doing the following problems. Check with your instructor on how best to use these resources. In many cases, the instructor wants you to understand how to do the calculations by hand. At the least, the software provides a check on your calculations. When calculations are particularly complex and the goal is interpreting the results in making decision, the software entirely replaces the manual calculations.

Master Production Scheduling

1. Complete the MPS record in Figure 11.29 for a single item.

FIGURE 11.29 MPS Record for Single Item

Item: A | **Order Policy:** 60 units | **Lead Time:** 1 week

Quantity on Hand: 35	Week 1	2	3	4	5	6	7	8
Forecast	20	18	28	28	23	30	33	38
Customer orders (booked)	15	17	9	14	9		7	
Projected on-hand inventory								
MPS quantity								
MPS start								

2. Complete the MPS record shown in Figure 11.30 for a single item.

FIGURE 11.30 MPS Record for Single Item

Item: A | **Order Policy:** 100 units | **Lead Time:** 1 week

	January				February			
Quantity on Hand: 75	1	2	3	4	5	6	7	8
Forecast	65	65	65	45	50	50	50	50
Customer orders (booked)	40	10	85		35	70		
Projected on-hand inventory								
MPS quantity								
MPS start								

3. An end item's demand forecasts for the next 10 weeks are 45, 45, 45, 45, 30, 30, 45, 45, 45, and 45 units. The current on-hand inventory is 150 units. The order policy is to produce in lots of 95. The booked customer orders for the item, starting with week 1, are 15, 48, 7, 5, 0, 3, 10, 0, 0, and 0 units. At present, no MPS quantities are on-hand for this item. The lead time is 2 weeks. Develop an MPS for this end item.

4. Figure 11.31 shows a partially completed MPS record for ball bearings.

a. Develop the MPS for ball bearings.

b. Four customer orders arrived in the following sequence:

Order	Quantity	Week Desired
1	500	4
2	400	5
3	300	1
4	300	7

Assume that you must commit to the orders in the sequence of arrival and cannot change the desired shipping dates or your MPS. Which orders should you accept?

5. Tabard Industries forecasted the following demand for one of its most profitable products for the next 8 weeks: 100, 100, 100, 80, 80, 80, 60, and 60 units. The booked customer orders for this product, starting in week 1 are: 90, 80, 50, 40, 20, 10, 0, and 0 units. The current on-hand inventory is 250 units, the order quantity is 200 units, and the lead time is one week.

a. Develop an MPS for this product.

b. The marketing department revised its forecast. Starting with week 1, the new forecasts are: 100, 100, 100, 120, 120, 120, 110, and 110 units. Assuming that the prospective MPS you developed in part (a) does not change, prepare a revised MPS record. Comment on the situation that Tabard now faces.

c. Returning to the original forecasted demand level and the MPS record you developed in part (a), assume that marketing accepted a new customer order for 100 units in week 2, and thereby booked orders in week 2 is now 180 units. Assuming that the prospective MPS you developed in part (a) does not change, prepare a revised MPS record. Comment on the situation that Tabard now faces.

Item: Ball bearings — **Order Policy:** 500 units; **Lead Time:** 1 week

Quantity on Hand: 400	Week 1	2	3	4	5	6	7	8	9	10
Forecast	550	300	400	450	300	350	200	300	450	400
Customer orders (booked)	300	350	250	250	200	150	100	100	100	100
Projected on-hand inventory										
MPS quantity	500									
MPS start										
Available-to-promise (ATP) inventory										

FIGURE 11.31
MPS Record for Ball Bearings

6. Figure 11.32 shows a partially completed MPS record for 2 inch pneumatic control valves. Suppose that you receive the following orders at right for the valves (shown in the order of their arrival). As they arrive, you must decide whether to accept or reject them. Which orders would you accept for shipment?

Order	Amount (Units)	Week Requested
1	15	2
2	30	5
3	25	3
4	75	7

FIGURE 11.32 ▶
MPS Record for 2'' Pneumatic Control Valve

Item: 2'' Pneumatic control valve						**Order Policy:** 75 units **Lead Time:** 1 week		
	Week							
Quantity on Hand: 10	1	2	3	4	5	6	7	8
Forecast	40	40	40	40	30	30	50	50
Customer orders (booked)	60	45	30	35	10	5	5	
Projected on-hand inventory								
MPS quantity	75	75						
MPS start	75							
Available-to-promise (ATP) inventory								

7. The forecasted requirements for an electric hand drill for the next 6 weeks are 15, 40, 10, 20, 50, and 30 units. The marketing department has booked orders totaling 20, 25, 10, and 20 units for delivery in the first (current), second, third, and fourth weeks. Currently, 30 hand drills are in stock. The policy is to order in lots of 60 units. Lead time is one week.
   a. Develop the MPS record for the hand drills.
   b. A distributor of the hand drills places an order for 15 units. What is the appropriate shipping date for the entire order?
8. A forecast of 320 units in January, 400 units in February, and 240 units in March has been approved for the seismic-sensory product family manufactured at the Rockport facility of Maryland Automated, Inc. Three products, A, B, and C, comprise this family. The product mix ratio for products A, B, and C for the past 2 years has been 35 percent, 40 percent, and 25 percent, respectively. Management believes that the monthly forecast requirements are evenly spread over the 4 weeks of each month. Currently, 15 units of product C are on hand. The company produces product C in lots of 40, and the lead time is 2 weeks. A production quantity of 40 units from the previous period is scheduled to arrive in week 1. The company has accepted orders of 25, 9, 11, 5, 4, and 9 units of product C in weeks 1 through 6, respectively. Prepare a prospective MPS for product C and calculate the available-to-promise inventory quantities.
9. An end item's demand forecasts for the next 6 weeks are 30 units, followed by forecasts of 25 units for weeks 7 through 10. The current on-hand inventory is 60 units. The order policy is to produce in lots of 100. The booked customer orders for the item, starting with week 1, are 22, 30, 15, 11, 0, 0, 9, 0, 0, and 0 units. The lead time is 2 weeks.
   a. Develop an MPS for this end item.
   b. The marketing department has received six orders for this item in the following sequence:

   Order 1 is for 40 units to be delivered in period 3

   Order 2 is for 60 units to be delivered in period 4

   Order 3 is for 70 units to be delivered in period 6

   Order 4 is for 40 units to be delivered in period 3

   Order 5 is for 20 units to be delivered in period 5

   Order 6 is for 115 units to be delivered in period 9

   Assuming that the prospective MPS you developed in part (a) does not change, which orders would you be able to accept based on the available to promise (ATP)?
10. An end item's demand forecasts for the next 10 weeks are 30, 30, 30, 30, 20, 20, 30, 30, 30, and 30 units. The current on-hand inventory is 100 units. The order policy is to produce in lots of 75. The booked customer orders for the item, starting with week 1, are 15, 38, 7, 5, 0, 3, 10, 0, 0, and 0 units. The lead time is 2 weeks.
    a. Develop an MPS for this end item.
    b. The marketing department has received five orders for this item in the following sequence:

    Order 1 is for 20 units to be delivered in period 1

    Order 2 is for 75 units to be delivered in period 4

    Order 3 is for 90 units to be delivered in period 6

Order 4 is for 75 units to be delivered in period 7

Order 5 is for 90 units to be delivered in period 10

Assuming that the prospective MPS you developed in part (a) does not change, which orders would you be able to accept based on the available to promise (ATP)?

MRP Explosion

11. Consider the bill of materials (BOM) in Figure 11.33.

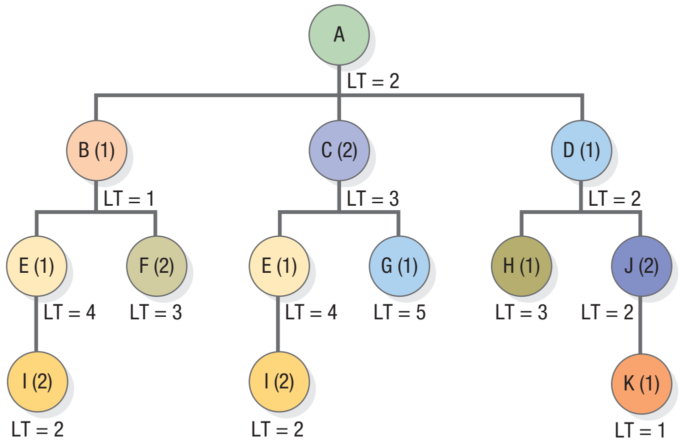
a. How many immediate parents (one level above) does item I have? How many immediate parents does item E have?

b. How many unique components does product A have at all levels?

c. Which of the components are purchased items?

d. How many intermediate items does product A have at all levels?

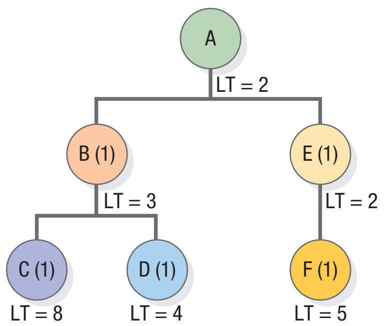
e. Given the lead times (LT) in weeks noted on Figure 11.33, how far in advance of shipment must a purchase commitment be for any of the purchased items identified in part (c)?



▲ **FIGURE 11.33**
BOM for Product A

12. Product A is made from components B, C, and D. Item B is a subassembly that requires two units of C and one unit of E. Item D also is an intermediate item, made from two units of F. All other usage quantities are two. Draw the BOM for product A.

13. What is the lead time (in weeks) to respond to a customer order for product A, based on the BOM shown in Figure 11.34, assuming no existing inventories or scheduled receipts?



▲ **FIGURE 11.34**
BOM for Product A

14. Product A is made from components B and C. Item B, in turn, is made from D and E. Item C also is an intermediate item, made from F and H. Finally, intermediate item E is made from H and G. Note that item H has two parents. The following are item lead times:

Item	A	B	C	D	E	F	G	H
Lead Time (weeks)	1	3	2	3	6	6	4	5

a. What lead time (in weeks) is needed to respond to a customer order for product A, assuming no existing inventories or scheduled receipts?

b. What is the customer response time if all purchased items (i.e., D, F, G, and H) are in inventory?

c. If you are allowed to keep just one purchased item in stock, which one would you choose?

15. Refer to Figure 11.23 and Solved Problem 1. If inventory consists of two units of B, one unit of F, and three units of G, how many units of G, E, and D must be purchased to produce five units of product A?

16. The partially completed inventory record for the tabletop subassembly in Figure 11.35 shows gross requirements, scheduled receipts, lead time, and current on-hand inventory.

a. Complete the last three rows of the record for an FOQ of 110 units.

b. Complete the last three rows of the record by using the L4L lot-sizing rule.

c. Complete the last three rows of the record by using the POQ lot-sizing rule, with $P = 2$.

17. The partially completed inventory record for the rotor subassembly in Figure 11.36 shows gross requirements, scheduled receipts, lead time, and current on-hand inventory.

a. Complete the last three rows of the record for an FOQ of 150 units.

b. Complete the last three rows of the record by using the L4L lot-sizing rule.

c. Complete the last three rows of the record by using the POQ lot-sizing rule, with $P = 2$.

18. The partially completed inventory record for the drive-shaft subassembly in Figure 11.37 shows gross requirements, scheduled receipts, lead time, and current on-hand inventory.

a. Complete the last three rows of the record for an FOQ of 50 units.

b. Complete the last three rows of the record by using the L4L lot-sizing rule.

c. Complete the last three rows of the record by using the POQ lot-sizing rule, with $P = 4$.

FIGURE 11.35 ▶
Inventory Record for the Tabletop Subassembly

Item: M405—X
Description: Tabletop subassembly
Lot Size:
Lead Time: 2 weeks

	Week									
	1	2	3	4	5	6	7	8	9	10
Gross requirements	90		85		80		45	90		
Scheduled receipts	110									
Projected on-hand inventory 40										
Planned receipts										
Planned order releases										

FIGURE 11.36 ▶
Inventory Record for the Rotor Subassembly

Item: Rotor subassembly
Lot Size:
Lead Time: 2 weeks

	Week							
	1	2	3	4	5	6	7	8
Gross requirements	65	15	45	40	80	80	80	80
Scheduled receipts	150							
Projected on-hand inventory 20								
Planned receipts								
Planned order releases								

FIGURE 11.37 ▶
Inventory Record for the Driveshaft Subassembly

Item: Driveshaft subassembly
Lot Size:
Lead Time: 3 weeks

	Week							
	1	2	3	4	5	6	7	8
Gross requirements	35	25	15	20	40	40	50	50
Scheduled receipts	80							
Projected on-hand inventory 10								
Planned receipts								
Planned order releases								

19. Figure 11.38 shows a partially completed inventory record for the real wheel subassembly. Gross requirements, scheduled receipts, lead time, and current on-hand inventory are shown.

a. Complete the last three rows of the record for an FOQ of 200 units.

b. Complete the last three rows of the record by using an FOQ of 100 units.

c. Complete the last three rows of the record by using the L4L rule.

Item: MQ–09
Description: Rear wheel subassembly
Lot Size:
Lead Time: 1 week

	Week									
	1	2	3	4	5	6	7	8	9	10
Gross requirements	25	105	110	90		45	110	60		
Scheduled receipts										
Projected on-hand inventory 50										
Planned receipts										
Planned order releases										

FIGURE 11.38 Inventory Record for the Rear Wheel Subassembly

20. A partially completed inventory record for the motor subassembly is shown in Figure 11.39.

a. Complete the last three rows of the record by using the L4L rule.

b. Complete the last three rows of the record by using the POQ rule with $P = 2$.

c. Complete the last three rows of the record by using the POQ rule with $P = 2$.

d. If it costs the company \$1 to hold a unit in inventory from one week to the next, and the cost to release an order is \$50, which of the lot sizing rules used above will provide the lowest inventory holding + order release cost?

Item: GF–4
Description: Motor subassembly
Lot Size:
Lead Time: 2 weeks

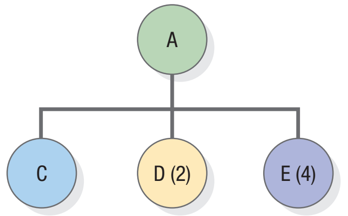
	Week									
	1	2	3	4	5	6	7	8	9	10
Gross requirements		80	50	35	20	55	15	30	25	10
Scheduled receipts	60									
Projected on-hand inventory 20										
Planned receipts										
Planned order releases										

FIGURE 11.39 Inventory Record for the Motor Subassembly

21. The BOM for product A is shown in Figure 11.40, and data from the inventory records are shown in Table 11.9. In the MPS for product A, the MPS start row has 100 units in week 3 and 200 in week 6. Develop the material requirements plan for the next 6 weeks for items C, D, and E.

a. Develop the material requirements plan for the next 6 weeks for items C, D, and E.

b. What specific managerial actions are required in week 1?



▲ **FIGURE 11.40**
BOM for Product A

TABLE 11.9 | INVENTORY RECORD DATA

	ITEM		
Data Category	**C**	**D**	**E**
Lot-sizing rule	L4L	FOQ = 200	POQ (P = 2 weeks)
Lead time	2 weeks	1 week	1 week
Scheduled receipts	None	200 (in week 3)	200 (in week 3)
Beginning inventory	50	200	0

22. The BOMs for products A & B and data from the inventory records are shown in Figure 11.41. Data from the inventory records are shown in Table 11.10. In the MPS for product A, the MPS start row has 85 units in week 2 and 200 in week 4 and 50 in week 8. In the MPS for product B, the MPS start row has 65 units in week 3 and 50 in week 4 and 50 in week 5 and 75 in week 8.

a. Develop the material requirements plan for the next 8 weeks for items C, D, and E. Note any difficulties you observe in the inventory records.

b. Can the difficulties noted in part (a) be rectified by expediting any Scheduled Receipts?

FIGURE 11.41 ▶
BOMs for Product A and Product B

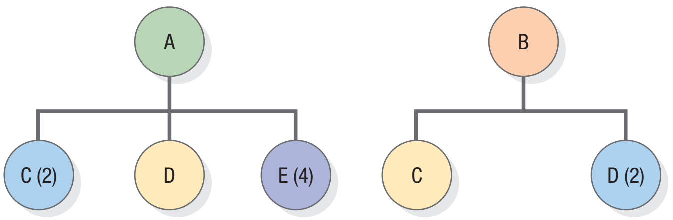


TABLE 11.10 | INVENTORY RECORD DATA

	ITEM		
Data Category	**C**	**D**	**E**
Lot-sizing rule	L4L	FOQ = 200	POQ (P = 2 weeks)
Lead time	2 weeks	1 week	1 week
Scheduled receipts	200 (in week 3)	0	0
Beginning inventory	0	0	200

23. Figure 11.42 illustrates the BOM for product A. The MPS start row in the MPS for product A calls for 50 units in week 2, 65 units in week 5, and 80 units in week 8. Item C is produced to make A and to meet the forecasted demand for replacement parts. Past replacement part demand has been 20 units per week (add 20 units to C's gross requirements). The lead times for items F and C are 1 week, and for the other items the lead time is 2 weeks. No safety stock is required for items B, C, D, E, and F. The L4L lot-sizing rule is used for items B and F; the POQ lot-sizing rule ($P = 2$) is used for C. Item E has an FOQ of 600 units, and D has an FOQ of 250 units. On-hand inventories are 50 units of B, 50 units of C, 120 units of D, 70 units of E, and 250 units of F. Item B has a scheduled receipt of 50 units in week 2. Develop a material requirements plan for the next 8 weeks for items B, C, D, E, and F.

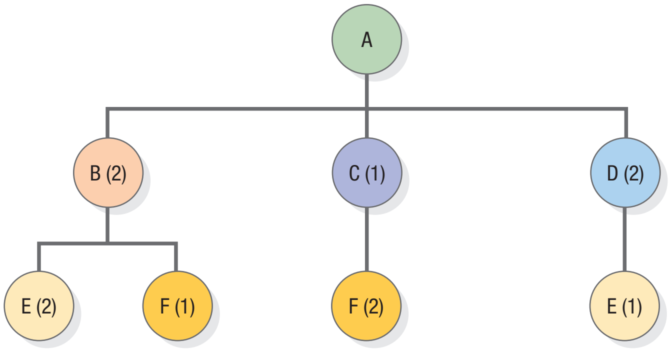


FIGURE 11.42
BOM for Product A

24. The following information is available for three MPS items:

Product A	An 80-unit order is to be started in week 3.
	A 55-unit order is to be started in week 6.
Product B	A 125-unit order is to be started in week 5.
Product C	A 60-unit order is to be started in week 4.

Develop the material requirements plan for the next 6 weeks for items D, E, and F. The BOMs are shown in Figure 11.43, and data from the inventory records are shown in Table 11.11. (*Warning:* A safety stock requirement applies to item F. Be sure to plan a receipt for any week in which the projected on-hand inventory becomes less than the safety stock.)

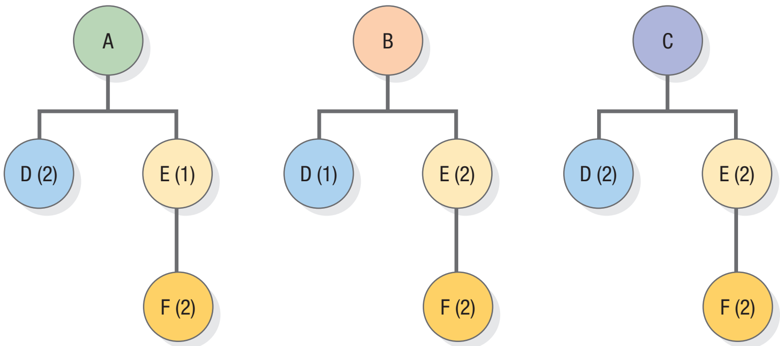


FIGURE 11.43
BOMs for Products A, B, and C

TABLE 11.11 | INVENTORY RECORD DATA

	ITEM		
Data Category	**D**	**E**	**F**
Lot-sizing rule	FOQ = 150	L4L	POQ (P = 2)
Lead time	3 weeks	1 week	2 weeks
Safety stock	0	0	30
Scheduled receipts	150 (week 3)	120 (week 2)	None
Beginning inventory	150	0	100

25. Figure 11.44 shows the BOMs for two products, A and B. Table 11.12 shows the MPS quantity start date for each one. Table 11.13 contains data from inventory records for items C, D, and E. There are no safety stock requirements for any of the items.

a. Determine the material requirements plan for items C, D, and E for the next 8 weeks.

b. What specific managerial actions are required in week 1?

c. Suppose that a very important customer places an emergency order for a quantity of product A. To satisfy this order, a new MPS of 200 units of product A is now required in week 5. Determine the changes to the material requirements plan if this order is accepted and note any problems that you detect.

FIGURE 11.44
BOMs for Products A and B

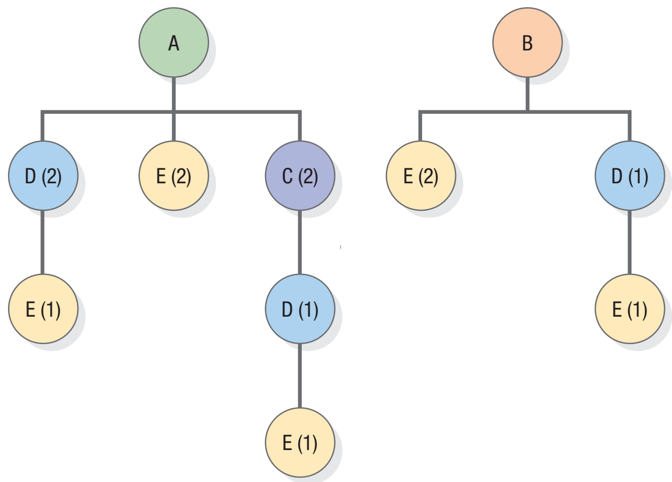


TABLE 11.12 | MPS QUANTITY START DATES

	DATE							
Product	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
A		125		95		150		130
B			80			70		

TABLE 11.13 | INVENTORY RECORD DATA

	ITEM		
Data Category	**C**	**D**	**E**
Lot-sizing rule	L4L	POQ ($P = 3$)	FOQ = 800
Lead time	3 weeks	2 weeks	1 week
Scheduled receipts	200 (week 2)	None	800 (week 1)
Beginning inventory	85	625	350

26. The BOM for product A is shown in Figure 11.45. The MPS for product A calls for 120 units to be started in weeks 2, 4, 5, and 8. Table 11.14 shows data from the inventory records.

a. Develop the material requirements plan for the next 8 weeks for each item.

b. What specific managerial actions are required in week 1? Make sure you address any specific difficulties you encounter in the inventory records.

FIGURE 11.45 ▶
BOM for Product A

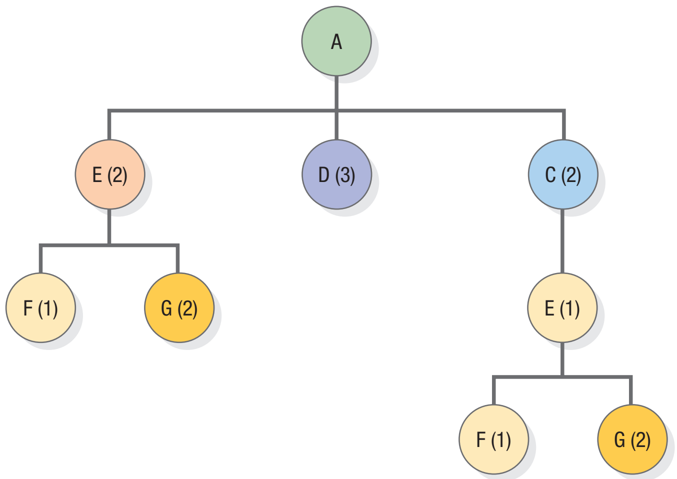


TABLE 11.14 | INVENTORY RECORD DATA

	ITEM				
Data Category	**C**	**D**	**E**	**F**	**G**
Lot-sizing rule	L4L	FOQ = 700	FOQ = 700	L4L	L4L
Lead time	3 weeks	3 weeks	4 weeks	2 weeks	1 week
Safety stock	0	0	0	50	0
Scheduled receipts	150 (week 2)	450 (week 2)	700 (week 1)	None	1,400 (week 1)
Beginning inventory	125	0	235	750	0

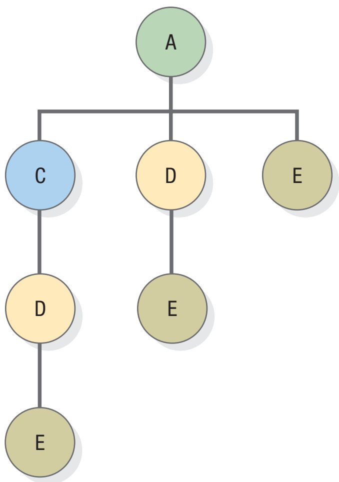
27. Refer to Solved Problem 1 (Figure 11.23) for the bill of materials and Table 11.15 for component inventory record information. Develop the material requirements plan for all components and intermediate items associated with product A for the next 10 weeks. The MPS for product A calls for 50 units to be started in weeks 2, 6, 8, and 9. (*Warning:* Safety stock requirements apply to items B and C.)

TABLE 11.15 | INVENTORY RECORD DATA

	ITEM					
Data Category	**B**	**C**	**D**	**E**	**F**	**G**
Lot-sizing rule	L4L	L4L	POQ ($P = 2$)	L4L	L4L	FOQ = 100
Lead time	2 weeks	3 weeks	3 weeks	6 weeks	1 week	3 weeks
Safety stock	30	10	0	0	0	0
Scheduled receipts	150 (week 2)	50 (week 2)	None	400 (week 6)	40 (week 3)	None
Beginning inventory	30	20	60	400	0	0

28. The bill of materials and the data from the inventory records for product A are shown in Figure 11.46. Assume that the MPS start quantities for A are 100 units in weeks 1, 2, 3, 4, 7, 8, 9, and 10. Derive an MRP plan for the components going into product A using the data in Table 11.16.

What specific managerial actions are required in week 1? Make sure you address any specific difficulties you encounter in the inventory records.

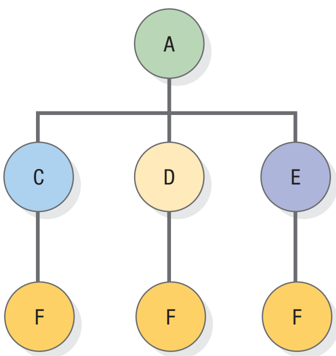


▲ **FIGURE 11.46**
BOM for Product A

TABLE 11.16 | INVENTORY RECORD DATA

	ITEM		
Data Category	**C**	**D**	**E**
Lot-sizing rule	L4L	L4L	FOQ = 300
Lead time	1 week	2 weeks	2 weeks
Scheduled receipts		100 (in week 2)	300 (in week 2)
Beginning inventory	225	350	100

29. The bill of materials and the data from the inventory records for product A are shown in Figure 11.47. Assume that the MPS start quantities for A are 50 units in weeks 1, 2, and 3, and 150 units in weeks 6 and 8. Derive an MRP plan for the components going into product A using the data in Table 11.17.



▲ **FIGURE 11.47**
BOM for Product A

TABLE 11.17 | INVENTORY RECORD DATA

	ITEM			
Data Category	**C**	**D**	**E**	**F**
Lot-sizing rule	POQ ($P = 2$)	L4L	FOQ = 300	FOQ = 400
Lead time	1 week	1 week	2 weeks	4 weeks
Scheduled receipts		100 (week 2)		400 (week 1)
Beginning inventory	100	0	110	40

Resource Planning for Service Providers

30. All Smiles Dental Clinic would like to develop a hygienist master schedule for the treatment of patients. Five full time hygienists are scheduled six days a week, and each hygienist can treat 10 patients per day. If the number of patients expected is greater than the hygienist capacity scheduled, additional hygienists may be hired on a daily basis from a temporary worker employment agency. The agency requires one day notice. Based on your knowledge of MPS, complete the following prototype schedule shown in Figure 11.48.

FIGURE 11.48 Hygienist Master Schedule

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Forecasted Patients	50	50	50	50	50	75
Booked Patients	45	60	25	25	50	40
Hygienists Scheduled						
Hygienists Required						
Hygienists Notified						

31. The McDuff Credit Union advertises their ability to quickly process personal loan applications for their members. As seen in Table 11.18, the loan process requires four steps and takes approximately eight working days to complete.

TABLE 11.18 LEAD TIME DATA FOR McDUFF CREDIT UNION

Personal Loan Approval Process	Lead time in Days
Level 1: Final Approval	1
Level 2: Loan Processing	3
Level 3: Pre-Approval	2
Level 4: Initial Application Screen	2
Total	8

To process a loan, the Credit Union requires accounting clerks, financial analysts and a branch manager. Table 11.19 provides the time required by each employee classification by process level.

TABLE 11.19 RESOURCE REQUIREMENT DATA FOR McDUFF CREDIT UNION

Personal Loan Approval Process – Resources Required	Accounting Clerk Hours Per Day	Financial Analyst Hours Per Day	Branch Manager Hours Per Day
Level 1: Final Approval	2.00	0.00	0.00
Level 2: Loan Processing	0.50	1.50	0.00
Level 3: Pre-Approval	1.00	0.20	0.00
Level 4: Initial Application Screen	0.00	1.00	1.00

Calculate the total hours of each resource that will be required by McDuff's if the following numbers of final loan approval applications are forecasted by the Credit Union for each working day over the next 12 days.

Day of the Month	1	2	3	4	5	6	7	8	9	10	11	12
Final Loan Approval Applications	5	5	7	8	2	2	4	6	2	1	6	3

32. The comprehensive regional hospital discussed in the section "Resource Planning for Service Providers" performs bypass surgery at its state-of-the-art facility. Similar to aneurysm repair, this procedure also requires the patient to proceed through seven levels of treatment as seen in the bill of resources in Figure 11.21(a). The amount of time it takes for a patient to move from one level of treatment to the next follows.

TABLE 11.20 LEAD TIME DATA

BOR Level	Lead Time in Days
Level 1	1
Level 2	1
Level 3	1
Level 4	2
Level 5	1
Level 6	2
Level 7	1
Total	9

The projected number of completed by-pass procedures over the next 15 days is shown in Table 11.21.

TABLE 11.21 PROJECTED PATIENT DEPARTURES FROM THE BYPASS PROCEDURE

Day of the Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Bypass Patients	2	3	2	2	2	3	0	3	2	3	4	3	2	0	3

Consider three critical resources of nurses, beds, and lab tests that are required at each level of treatment as shown in Table 11.22.

a. Use the above information to calculate the daily resource requirements (similar to gross requirements on a material record) for each resource to treat bypass patients at this regional hospital.

b. What are the 15-day resource requirements to treat both aneurysm patients and bypass patients?

TABLE 11.22 RESOURCE REQUIREMENT DATA

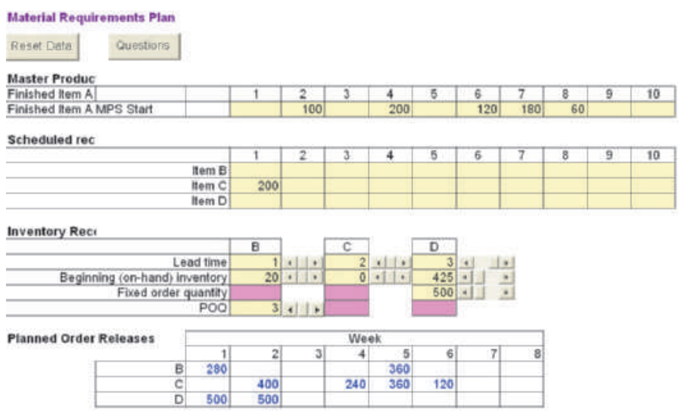
Resources Required for Bypass Patients	Nurse Hours Required Per Patient Per Day	Beds Required Per Patient Per Day	Lab Tests Required Per Patient Per Day
Level 1	0	0	0
Level 2	2	1	0
Level 3	8	1	2
Level 4	12	1	4
Level 5	22	1	1
Level 6	12	1	4
Level 7	1	0	0

Active Model Exercise

This Active Model appears in MyOMLab. It allows you to evaluate the relationship between the inventory record data and the planned order releases.

QUESTIONS

1. Suppose that the POQ for item B is changed from 3 weeks to 2 weeks. How does this change affect the order releases for items B, C, and D?
2. As the on-hand inventory for item C increases from 0 to 200, what happens to the order releases for items B, C, and D?
3. As the fixed order quantity (FOQ) for item D increases from 500 to 750, what happens to the order releases for items B, C, and D?
4. As the lead time for item C changes, what happens to the order releases for items B, C, and D?



▲ **ACTIVE MODEL**
Material Requirements Planning Using Data from Solved Problem 3 and Table 11.4

CASE Flashy Flashers, Inc.

Flashy Flashers is a medium-sized firm employing 900 persons and 125 managerial and administrative personnel. The firm produces a line of automotive electrical components. It supplies about 95 auto parts stores and Moonbird Silverstreak car dealers in its region. Johnny Bennett, who serves as the president, founded the company by producing cable assemblies in his garage. By working hard, delivering consistent product quality, and by providing good customer service, he expanded his business to produce a variety of electrical components. Bennett's commitment to customer service is so strong that his company motto, "Love Thy Customers as Thyself," is etched on a big cast-iron plaque under his giant oil portrait in the building's front lobby.

The company's two most profitable products are the automotive front sidelamp and the headlamp. With the rising popularity of Eurosport sedans, such as the Moonbird Silverstreak, Flashy Flashers has enjoyed substantial demand for these two lamp items.

Last year, Kathryn Marley, the vice president of operations and supply chain management, approved the installation of a new MRP system. It is a first important step toward the eventual goal of a full-fledged ERP system. Marley worked closely with the task force that was created to bring MRP online. She frequently attended the training sessions for selected employees, emphasizing how MRP should help Flashy Flashers secure a better competitive edge.

A year later, the MRP system is working fairly well. However, Marley believes that there is always a better way and seeks to continually improve the company's processes. To get a better sense for potential improvements, she met with the production and inventory control manager, the shop supervisor, and the purchasing manager. Here are some of their observations.

Production and Inventory Control Manager

Inventory records and BOM files are accurate and well maintained. Inventory transactions are faithfully made when inventory is replenished or removed from the stockroom so that current on-hand balances are credible. There is an MRP explosion each week, which gives the company the new MRP. It provides information that helps identify when new orders need to be launched. Information can also be searched to help identify which scheduled receipts need to be expedited and which ones can be delayed by assigning them a later due date, thereby making room for more urgent jobs.

One planner suggested that the MRP outputs should be extended to provide priority and capacity reports, with pointers as to which items need their attention. The original plan was to get the order-launching capability implemented first. However, there is no formal system of priority planning, other than the initial due date assigned to each scheduled receipt when it is released, transforming it from a planned order release into a scheduled receipt. The due dates do not get updated later even when there are unexpected scrap losses, capacity shortages, short shipments, or last-minute changes in the MPS (responding to requests from favorite customers). Jobs are scheduled on the shop floor and by suppliers according to the EDD rule, based on their due dates. If due dates assigned to scheduled receipts were updated, it might help get open orders done when they are really needed. Furthermore, planned order releases in the action bucket are translated into scheduled receipts (using inventory transactions), after checking that its components are available. The current system does not consider possible capacity problems when releasing new orders.

Shop Supervisor

His primary complaint is that the shop workloads are anything but level. One week, they hardly have any work, and the supervisor overproduces (more than called for by the scheduled receipts) just to keep everyone busy. The next week can be just the opposite—so many new orders with short fuses that almost everyone needed to work overtime or else the scheduled receipt quantities are reduced to cover immediate needs. It is feast or famine, unless they make things work on the shop floor! They do make inventory transactions to report deviations from plan for the scheduled receipts, but these "overrides" make the scheduled receipt information in the MRP records more uncertain for the planners. A particular concern is to make sure that the bottleneck workstations are kept busy.

Purchasing

Buyers are putting out too many fires, leaving little time for creative buying. In such cases, their time is spent following up on orders that are required in the very near future or that are even late. Sometimes, the MRP plan shows planned order releases for purchased items that that are needed almost immediately, not allowing for the planned lead time. In checking the MRP records, the planned lead times are realistic and what the suppliers expect. Last week, things were fine for an item, and this week a rush order needs to be placed. What is the problem?

Marley tried to assimilate all this information. She decided to collect all the required information about the sidelamps and headlamps (shown in Table 11.24 through Table 11.26 and in Figure 11.49) to gain further insight into possible problems and identify areas for improvement.

Your Assignment

Put yourself in Marley's place and prepare a report on your findings. Specifically, you are required to do a manual MRP explosion for the sidelamps and

TABLE 11.23 | PART NUMBERS AND DESCRIPTIONS

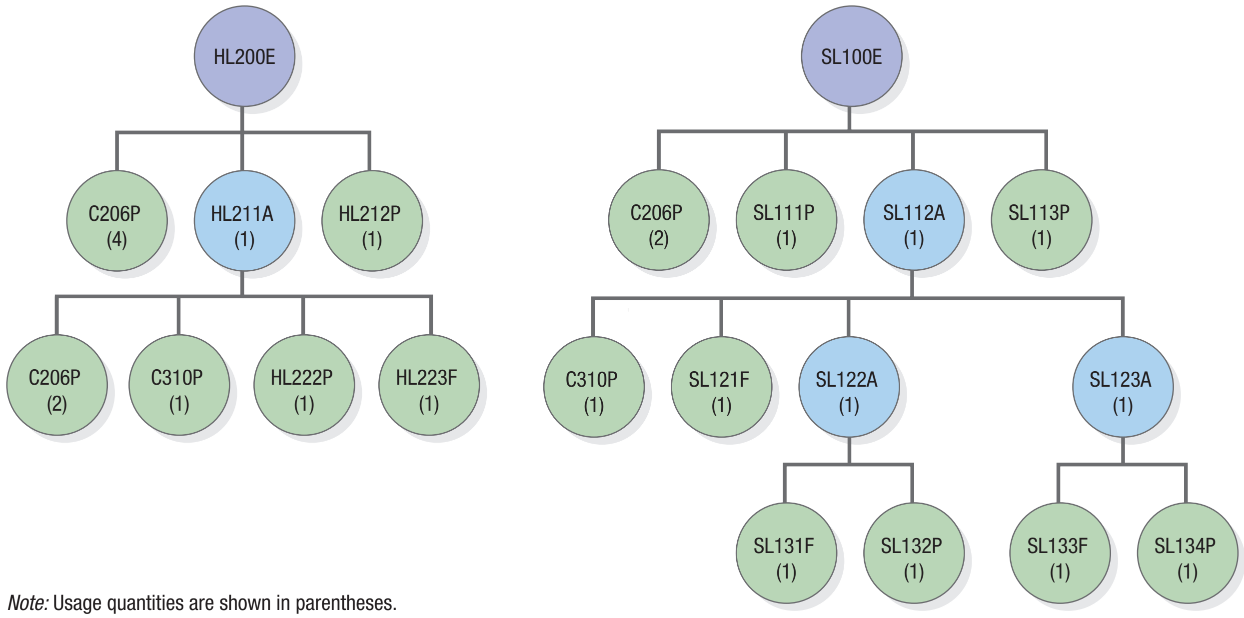
Part Number	Description
C206P	Screws
C310P	Back rubber gasket
HL200E	Headlamp
HL211A	Head frame subassembly
HL212P	Head lens
HL222P	Headlamp module
HL223F	Head frame
SL100E	Sidelamp
SL111P	Side lens
SL112A	Side frame subassembly
SL113P	Side lens rubber gasket
SL121F	Side frame
SL122A	Side bulb subassembly
SL123A	Flasher bulb subassembly
SL131F	Side cable grommet and receptacle
SL132P	Side bulb
SL133F	Flasher cable grommet and receptacle
SL134P	Flasher bulb

TABLE 11.24 | MASTER PRODUCTION SCHEDULE

Item Description and Part Number	Quantity	MPS Start Date
Headlamp (HL200E)	120	Week 4
	90	Week 5
	75	Week 6
Sidelamp (SL100E)	100	Week 3
	80	Week 5
	110	Week 6

TABLE 11.25 | REPLACEMENT PART DEMAND

Item Description and Part Number	Quantity	Date
Side lens (SL111P)	40	Week 3
	35	Week 6



Note: Usage quantities are shown in parentheses.

FIGURE 11.49
BOMs for Headlamps and Sidelamps

TABLE 11.26 | SELECTED DATA FROM INVENTORY RECORDS

Part Number	Lead Time (Weeks)	Safety Stock (Units)	Lot-Sizing Rule	On-Hand (Units)	Scheduled Receipt (Units and Due Dates)
C206P	1	30	FOQ = 2,500	270	—
C310P	1	20	FOQ = 180	40	180 (week 1)
HL211A	3	0	L4L	0	
HL212P	2	15	FOQ = 350	15	—
HL222P	3	10	POQ(P = 4 weeks)	10	285 (week 1)
HL223F	1	0	POQ(P = 4 weeks)	0	120 (week 1)
SL111P	2	0	FOQ = 350	15	—
SL112A	3	0	L4L	20	80 (week 2)
SL113P	1	20	FOQ = 100	20	—
SL121F	2	0	L4L	0	80 (week 2)
SL122A	2	0	L4L	0	80 (week 2)
SL123A	2	0	FOQ = 200	0	—
SL131F	2	0	POQ(P = 2 weeks)	0	110 (week 1)
SL132P	1	25	FOQ = 100	35	100 (week 1)
SL133F	2	0	FOQ = 250		—
SL134P	1	0	FOQ = 400	100	—

Source: This case was originally prepared by Professor Soumen Ghosh, Georgia Institute of Technology, for the purpose of classroom discussion only.

headlamps for the next 6 weeks (beginning with the current week). Assume that it is now the start of week 1. Fill in the planned order releases form provided in Table 11.27. It should show the planned order releases for all items for the next 6 weeks. Include it in your report.

Supplement your report with worksheets on the manual MRP explosion, and list the actions that planners should consider this week to (1) release new orders, (2) expedite scheduled receipts, and (3) delay a scheduled receipt's due date.

Finally, identify the good and bad points of MRP implementation at Flashy Flashers. Conclude by making suggestions on ways to improve its resource planning process.

TABLE 11.27 PLANNED ORDER RELEASE FORM

FILL IN THE PLANNED ORDER RELEASES FOR ALL COMPONENTS.

	Week					
Item Description and Part Number	**1**	**2**	**3**	**4**	**5**	**6**
Side lens (SL111P)						
Side lens rubber gasket (SL113P)						
Side frame subassembly (SL112A)						
Side frame (SL121F)						
Side bulb subassembly (SL122A)						
Flasher bulb subassembly (SL123A)						
Side cable grommet and receptacle (SL131F)						
Flasher cable grommet and receptacle (SL133F)						
Side bulb (SL132P)						
Flasher bulb (SL134P)						
Head frame subassembly (HL211A)						
Head lens (HL212P)						
Headlamp module (HL222P)						
Head frame (HL223F)						
Back rubber gasket (C310P)						
Screws (C206P)						

Geoffrey Robinson/Alamy

To compete with bricks-and-mortar competitors, Amazon has to have ample inventories at strategically located facilities to support the competitive priority of delivery speed. Here an employee in the Amazon fulfillment center in Milton Keynes, England is scanning inventory in preparation for Cyber Monday, 2012.

12

DESIGNING EFFECTIVE SUPPLY CHAINS

Amazon.com

Amazon.com is a $76 billion company specializing in the online retail business. It has 96 fulfillment centers and employs 117,000 employees worldwide to deliver enormous volumes of packages of diverse products to an international clientele. On its busiest day in 2012, customers ordered more than 26.5 million items, or about 306 items per second, only 57 percent of which were in North America. Seasonality in demand patterns, customers demanding variety in product selection, and many brick-and-mortar stores offering stiff competition: if there is ever a situation where supply chain design is important, this is it.

Competing against the likes of Walmart, Target, and Best Buy is a challenging task. All have retail stores as well as an online presence. At brick-and-mortar retail stores customers can see the products they are interested in and experience instant gratification in obtaining the item the second it is bought. Also, Best Buy and Walmart, for example, use their store locations as distribution hubs for online orders, cutting their delivery times to two days or less, which is quicker than having them shipped from warehouses located across the country.

How can Amazon compete? There are four key competitive priorities for its supply chain: delivery speed, variety, customization, and low-cost operations. Amazon has achieved delivery speed by strategically locating its distribution facilities and adding more capacity, adding more than 1,300 robots to its line to help get packages out the door faster, increasing the items held in stock to support delivery speed while not over-investing in slow moving items, and working with manufacturers and distributors to ship products directly to customers for those items not in stock, a practice known as *drop shipping*. To further reduce the time between a customer's order and delivery of the products, Amazon has initiated a program to use the United States Postal Service to make Sunday home deliveries.

As for variety, customers shopping on Amazon.com have access to literally tens of millions of products. For example, a blank search of home and kitchen products on Amazon's website yields over 17 million hits, and that is only one of 38 departments a customer can shop. Only a fraction of these items are stocked in Amazon's warehouses, which puts a high priority on coordination with manufacturers and distributors. Customization is the ability to provide the specific, unique order each customer wants. The distribution process is initiated by a customer ordering from the Amazon.com website or an affiliate website. The system determines which distribution center to ship the item from or whether to use a drop shipper, who uses Amazon packaging and delivers the item directly to the customer. The decision is determined by product availability and transportation costs. Several items for an order may come from different sources, in which case they are amalgamated at transportation hubs before final delivery. Amazon is practicing *mass customization* and is using an *assemble-to-order* supply chain design. Finally, price is a major order winner for Amazon. Low prices are supported by low-cost operations in the supply chain. High volumes put a downward pressure on per-unit prices from manufacturers and distributors. Further, Amazon's revenues do not have to support operations at retail outlets, thereby saving the overhead associated with them. Finally, the high costs of transportation and shipping has forced Amazon to carefully design their supply chains with logistics in mind, such as the use of its own fleet in some of its major markets.

Supporting the four competitive priorities requires Amazon to design a supply chain that is agile and able to produce unique customer orders on a timely basis.

Sources: Mae Anderson and Anne D'Innocenzio, "Amazon vs. Stores: The Holiday Battle Heats Up," Associated Press, Naples Daily News (Thursday, November 28, 2013), pp. 2B; Jay Greene, "Amazon.com Cuts Deal with USPS," Associated Press, Naples Daily News (Tuesday, November 12, 2013), pp. 5A–5B; Mark Solomon, "Amazon Plans Revamp of U.S. Shipping with Mix of Private Fleet, Regional Carriers, and USPS," DC Velocity, (March 6, 2014), pp. 1–3; "Company Analysis: Team C2X 'Amazon.com,' " National Institute of Industrial Engineering, Powai, Mumbai, India (2012), pp. 3–20; Amazon.com 2013 Annual Report, **http://phx.corporate-ir.net** (2014).

LEARNING GOALS *After reading this chapter, you should be able to:*

1. Explain the strategic importance of supply chain design.
2. Identify the nature of supply chains for service providers as well as for manufacturers.
3. Calculate the critical supply chain performance measures.
4. Explain how efficient supply chains differ from responsive supply chains and the environments best suited for each type of supply chain
5. Explain the strategy of mass customization and its implications for supply chain design.
6. Analyze a make-or-buy decision using break-even analysis.

Amazon.com is an excellent example of how a supply chain can be successfully tailored to customer needs in a highly competitive market. A *supply chain* is the interrelated series of processes within a firm and across different firms that produces a service or product to the satisfaction of customers. More specifically, it is a network of service, material, monetary, and information flows that link a firm's customer relationship, order fulfillment, and supplier relationship processes to those of its suppliers and customers. It is important to note, however, that a firm such as Amazon may have multiple supply chains, depending on the mix of products it buys and sells. A supplier in one supply chain may not be a supplier in another supply chain because the product may be different or the supplier may simply be unable to negotiate a successful contract.

Creating an Effective Supply Chain

Creating an effective supply chain involves the recognition of external competitive pressures as well as internal organizational pressures from groups such as sales, marketing, and product development. These pressures are (1) dynamic sales volumes, (2) customer service and quality expectations, (3) service/product proliferation, and (4) emerging markets.

Dynamic sales volumes One of the most costly operating aspects of supply chains is trying to meet the needs of volatile sales volumes. Often this involves excessive inventories, underutilized personnel, or more expensive delivery options to meet customer demands on time. While sometimes these volatile demands are caused by external sources such as the customers themselves, they are often caused internally by end-of-month sales promotions. Supply chain design should involve close collaboration between top-level managers across the organization so that unnecessary costly supply chain options are avoided. We will discuss the implications of supply chain dynamics in more depth in Chapter 14, “Integrating the Supply Chain.”

Customer service and quality expectations We have discussed customer service levels as they relate to an organization’s internal inventories in Chapter 9, “Managing Inventories.” Here we focus on the organizational pressures emanating from the sales and marketing groups for superior service levels for the organization’s customers. Questions such as “What service level should be guaranteed?” or “How speedy must our deliveries be?” need collaborative discussion from the sales, marketing, and finance groups. Customers are also demanding stricter conformance to service or product specifications and higher levels of quality. “What levels of quality are achievable and at what cost?” The answers to these questions impinge on the design of the supply chain, particularly its points of supply and the choice of suppliers.

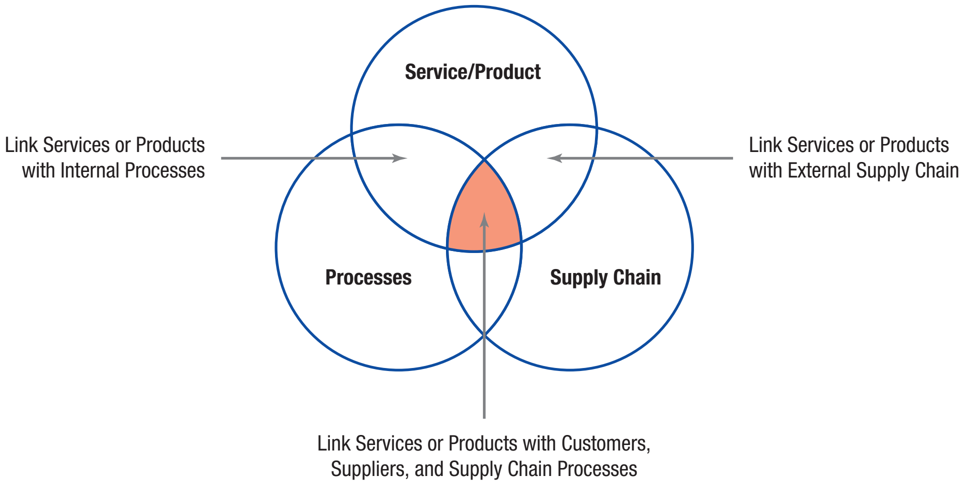
Service/product proliferation The sales and marketing groups provide the momentum to create new services or products because they are closely in touch with customers and their needs. The survival of any organization depends on the development of new markets. However, adding more services or products often adds complexity to the supply chain. It is not an unusual circumstance to find that a relatively large proportion of SKUs contribute only a small percentage of the revenues. Generally, these niche services or products have low volumes and therefore cost more to produce, market, and deliver. A thoughtful balance needs to be struck between the cost of operating the supply chain and the need to market new services and products.

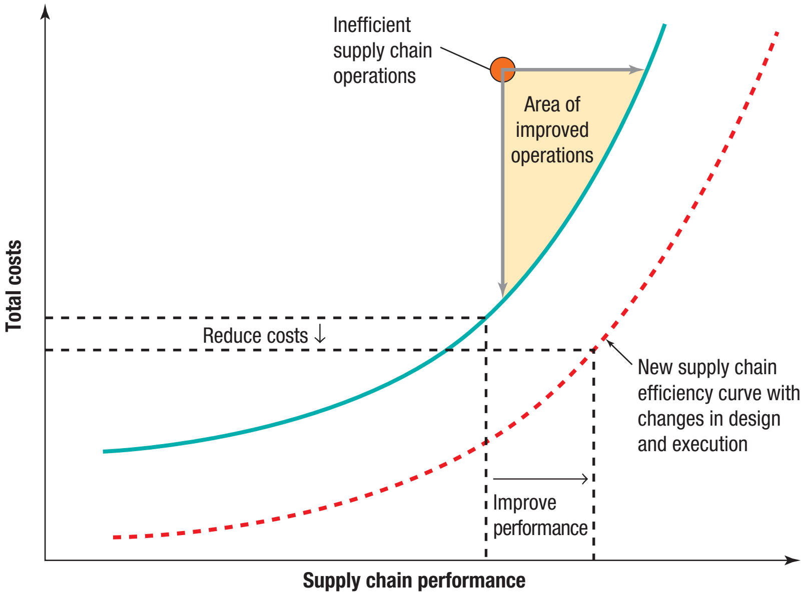
Emerging markets The increasing importance of emerging markets and the roles they play in the global market emphasizes the pressure on critical resources such as iron ore, agricultural commodities, and labor. For example, differing growth rates or internal strife across various emerging markets means that rising labor costs can quickly change the attractiveness of manufacturing facilities. Emerging markets also represent pools of new customers who demand products with lower price points. Such was the case with Gillette who produced a lost-cost razor as an entry to the Indian market. The health of the global economy often determines the need to examine the design of an organization’s supply chains.

The design of an effective supply chain must be a collaborative effort from the CEO down if it is to meet the four pressures. All functional areas have a stake in an organization’s supply chains. The firm’s operations strategy and competitive priorities guide its supply chain choices. Figure 12.1 shows the three major areas of focus in creating an effective supply chain.

1. *Link Services or Products with Internal Processes.* Parts 1 and 2 of this text have shown how firms coordinate internal process decisions with the competitive priorities of the services or products covered in the operations strategy.

▼ **FIGURE 12.1**
Creating an Effective Supply Chain





▲ **FIGURE 12.2**
Supply Chain Efficiency Curve

MyOMLab Animation

supply chain design

Designing a firm's supply chain to meet the competitive priorities of the firm's operations strategy.

2. *Link Services or Products with the External Supply Chain.* The competitive priorities assigned to the firm's services or products must be reflected in the design of the network of suppliers.
3. *Link Services or Products with Customers, Suppliers, and Supply Chain Processes.* The firm's processes that enable it to develop what customers want, interact with suppliers, deliver services or products, interact with customers, address environmental and ethical issues, and provide the information and planning tools needed to execute the operations strategy are the glue that binds the effective supply chain.

Supply chain management, the synchronization of a firm's processes with those of its suppliers and customers to match the flow of materials, services, and information with demand, is a critical skill in most organizations. A key part of supply chain management is **supply chain design**, which seeks to design a firm's supply chain to meet the competitive priorities of the firm's operations strategy. To get a better understanding of the importance of supply chain design, consider Figure 12.2, which conceptually shows the challenges facing supply chain managers. The **blue** line is an *efficiency curve*, which shows the trade-off between costs and performance for the current supply chain design if the supply chain is operated as efficiently as it can be. Now, suppose that your firm plots its actual costs and performance, as indicated by the **red** dot. It is far off of the efficiency curve, which is not an uncommon occurrence. Perhaps the performance is due to the four pressures mentioned above, which have been left unchecked for a period of time. The challenge is to move operations into the tinted area, as close to the **blue** curve as possible, which can be accomplished by better forecasting, inventory management, operations planning and scheduling, and resource planning, all of which we have already discussed in previous chapters. However, quantum steps in improvement can be obtained by improving the design of the supply chain in accordance with a sound operations strategy, which moves the curve as shown by the dashed **red** line. The goal is to reduce costs as well as increase performance.

What options are available to design a supply chain that best meets an organization's needs? Supply chain design options can be placed into four categories:

1. Strategic options, which include linking supply chain designs to competitive priorities, mass customization, and outsourcing decisions. These topics are discussed in this chapter.
2. Logistical network options, which include facility locations and inventory placement in the network of material flows. See Chapter 13, "Supply Chains and Logistics" for details.
3. Integration options, which include designs to mitigate supply chain dynamics and risk, supply chain collaboration to link major processes, and supplier selection. Chapter 14, "Integrating the Supply Chain," discusses this important set of issues.
4. Sustainability options, which include designs for environmental concerns and disaster relief. See Chapter 15, "Managing Supply Chain Sustainability," for insights into the considerations managers must make in this important area.

Before we get into the discussion of strategic issues, we first differentiate supply chains for services and manufacturing firms and discuss the major inventory and financial measures firms use to monitor the performance of their supply chains.

Supply Chains for Services and Manufacturing

Every firm or organization is a member of some supply chain. In this section, we show the similarities and differences between supply chains for services and manufacturing.

Services

Supply chain design for a service provider is driven by the need to provide support for the essential elements of the various services it delivers. Consider the example of Flowers-on-Demand, a florist with 27 retail stores in the greater Boston metropolitan area.[1] Customers can place orders for customized floral arrangements by visiting one of the stores, using a toll-free number, or going to the florist's Web page.

[1]The florist depicted is real; however, the name has been changed.

The 800 number and the Web page are operated by a local Internet services company, which takes orders and relays them to the florist. The arrangements are produced at a distribution center, and deliveries are made using either local couriers, or FedEx, if the delivery is outside of the Boston area. Fresh flowers, flown in from all over the world, are used in the arrangements.

What differentiates Flowers-on-Demand from floral wire services, such as Teleflora or FTD, is that it assembles all the arrangements and can ship out-of-area orders for next-day delivery anywhere in the country. To do business, the florist must have a supply chain that provides retail stores, a delivery center, computers, point-of-sale equipment, and employees. It must purchase flowers that are sourced globally as well as arrangement materials, such as pots, baskets, greeting cards, and packing materials. The florist must arrange the flowers per the customer's order and ensure that the arrangement is delivered as specified by the customer, using local services or FedEx. The design of its supply chain must provide convenience, which is facilitated by the location of the retail outlets and the opportunity to place orders via the Internet or the toll-free number.


Chuck Pefley/Alamy

An employee at a warehouse for a commercial flower farm packages flowers for local delivery. The farm acts as a supplier to grocery stores and retail florists.

Figure 12.3 illustrates a simplified supply chain for the florist. Each of the suppliers, of course, has its own supply chain (not shown). For example, the supplier for the arrangement materials may get baskets from one supplier and pots from another. The suppliers in the florist's supply chain play an integral role in its ability to meet its competitive priorities, such as top quality, delivery speed, and customization.

Manufacturing

A fundamental purpose of supply chain design for manufacturers is to control inventory by managing the flow of materials. The typical manufacturer spends more than 60 percent of its total income from sales on purchased services and materials, whereas the typical service provider spends only 30 to 40 percent. Because materials comprise such a large component of the sales dollar, manufacturers can reap large profits with a small reduction in the cost of materials, which makes supply chain management a key competitive weapon.

The supply chain for a manufacturing firm can be complicated, as Figure 12.4 illustrates. However, the supply chain depicted is an oversimplification because many companies have hundreds, if not thousands, of suppliers. In this example, the firm is in the U.S. and deals with an international supply chain. In addition, it owns its distribution and transportation services. Suppliers are often identified by their position in the supply chain. Here, tier 1 suppliers provide major subassemblies that are assembled by the manufacturing firm, tier 2 suppliers provide tier 1 suppliers with components, and so on. Not all

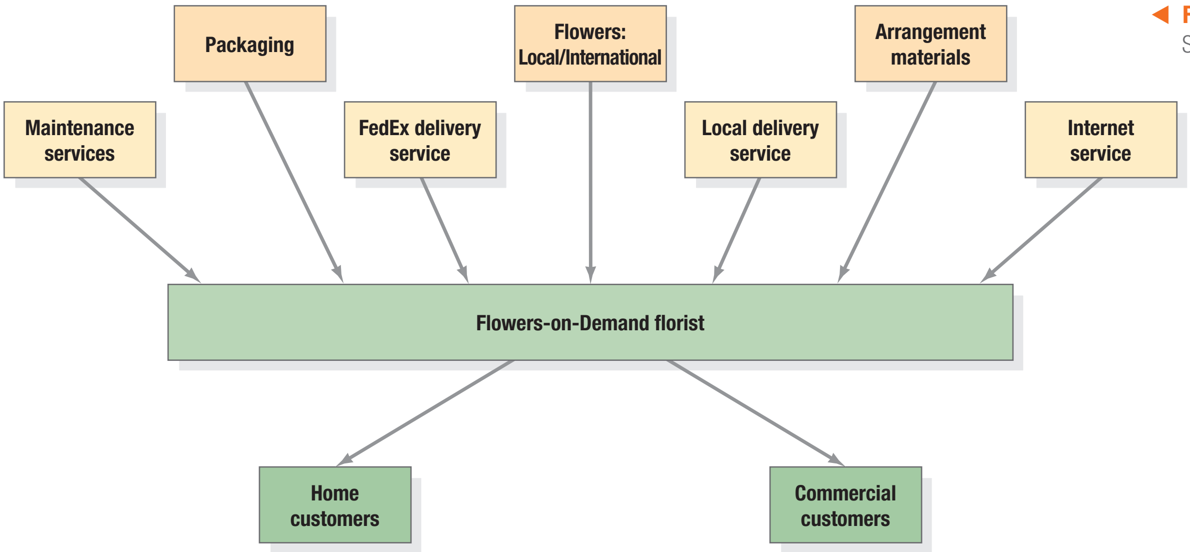


FIGURE 12.3
Supply Chain for a Florist

companies have the same number of levels in their supply chains. For example, companies that engineer products to customer specifications normally do not have distribution centers as part of their supply chains. Such companies often ship products directly to their customers.

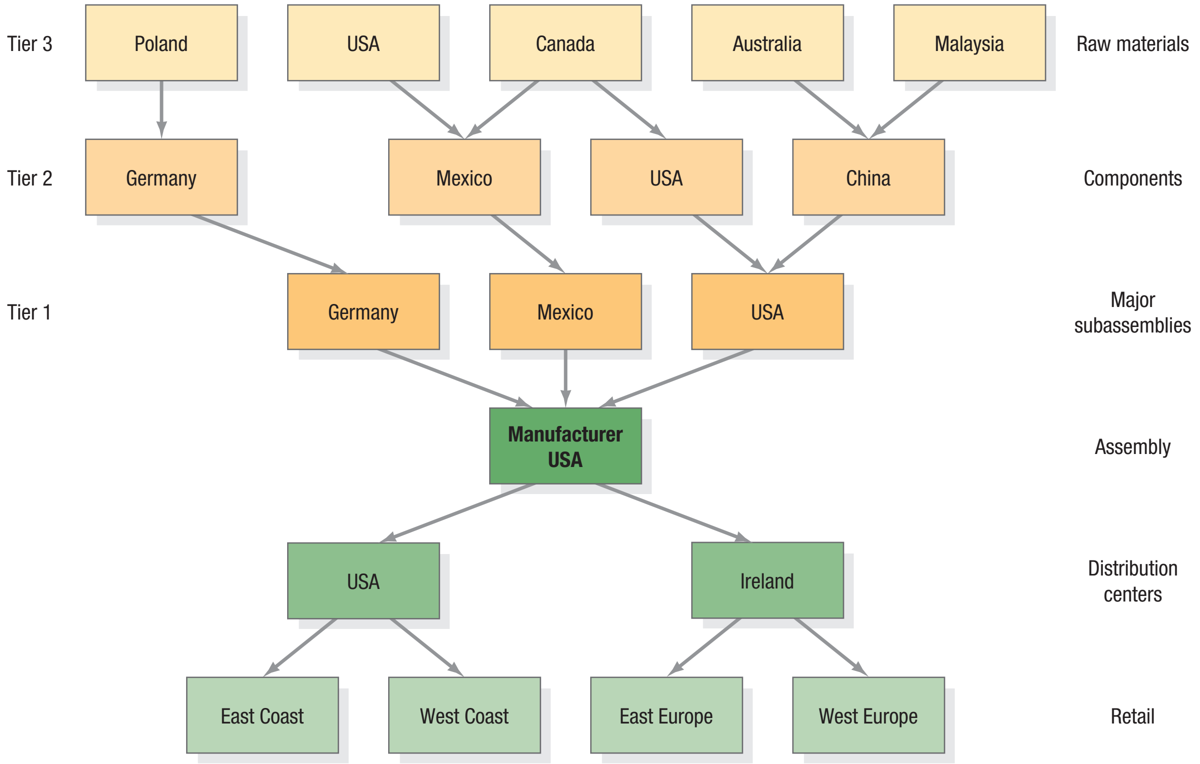


FIGURE 12.4 Supply Chain for a Manufacturing Firm

Measuring Supply Chain Performance

Regardless of whether the supply chain supports services or manufacturing, managers need performance measures to assess the implications of changes to supply chains. Before discussing the major supply chain design decisions, we define the typical inventory measures and financial measures used to monitor supply chain performance and evaluate alternative supply chain designs.

Inventory Measures

All methods of measuring inventory begin with a physical count of units, volume, or weight. However, measures of inventories are reported in three basic ways: (1) average aggregate inventory value, (2) weeks of supply, and (3) inventory turnover.

average aggregate inventory value
The total average value of all items held in inventory for a firm.

The **average aggregate inventory value** is the total average value of all items held in inventory by a firm. We express the dollar values in this inventory measure at cost because we can then sum the values of individual items in raw materials, work-in-process, and finished goods. Final sales dollars have meaning only for final services or products and cannot be used for all inventory items. It is an average because it usually represents the inventory investment over some period of time. Suppose a retailer holds items A and B in stock. One unit of item A may be worth only a few dollars, whereas one unit of item B may be valued in the hundreds of dollars because of the labor, technology, and other value-added operations performed in manufacturing the product. This measure for an inventory consisting of only items A and B is

weeks of supply
An inventory measure obtained by dividing the average aggregate inventory value by sales per week at cost.

$$\begin{array}{c}\text{Average aggregate}\\ \text{inventory value}\end{array} = \left(\begin{array}{c}\text{Number units of item A}\\ \text{typically on hand}\end{array}\right)\left(\begin{array}{c}\text{Value of each}\\ \text{unit of item A}\end{array}\right) + \left(\begin{array}{c}\text{Number of units of item B}\\ \text{typically on hand}\end{array}\right)\left(\begin{array}{c}\text{Value of each}\\ \text{unit of item B}\end{array}\right)$$

inventory turnover
An inventory measure obtained by dividing annual sales at cost by the average aggregate inventory value maintained during the year.

Summed over all items in an inventory, this total value tells managers how much of a firm's assets are tied up in inventory. Manufacturing firms typically have about 25 percent of their total assets in inventory, whereas wholesalers and retailers average about 75 percent.

To some extent, managers can decide whether the aggregate inventory value is too low or too high by historical or industry comparisons or by managerial judgment. However, a better performance measure would take demand into account because it would show how long the inventory resides in the firm. **Weeks of supply** is an inventory measure obtained by dividing the average aggregate inventory value by sales per week at cost. (In some low-inventory operations, days or even hours are a better unit of time for measuring inventory.) The formula (expressed in weeks) is

$$\text{Weeks of supply} = \frac{\text{Average aggregate inventory value}}{\text{Weekly sales (at cost)}}$$

Although the numerator includes the value of all items a firm holds in inventory (raw materials, WIP, and finished goods), the denominator represents only the finished goods sold—at cost rather than the sale price after markups or discounts. This cost is referred to as the *cost of goods sold*.

Inventory turnover (or *turns*) is an inventory measure obtained by dividing annual sales at cost by the average aggregate inventory value maintained during the year, or

$$\text{Inventory turnover} = \frac{\text{Annual sales (at cost)}}{\text{Average aggregate inventory value}}$$

The "best" inventory level, even when expressed as turnover, cannot be determined easily. A good starting point is to benchmark the leading firms in an industry.

Alistair Berg/Getty Images

Just looking at the size of an inventory does not reveal if it is a problem or an important element of a firm's strategy. Measures such as weeks of inventory or inventory turnover, relative to the industry, are needed. Here a distribution center is storing boxes of clothing, which have an industry average of about five turns per year.

EXAMPLE 12.1 Calculating Inventory Measures

The Eagle Machine Company averaged $2 million in inventory last year, and the cost of goods sold was $10 million. Figure 12.5 shows the breakout of raw materials, work-in-process, and finished goods inventories. The best inventory turnover in the company's industry is six turns per year. If the company has 52 business weeks per year, how many weeks of supply were held in inventory? What was the inventory turnover? What should the company do?

MyOMLab

Tutor 12.1 in MyOMLab provides a new example to practice the calculation of inventory measures.

Cost of Goods Sold	$10,000,000
Weeks of Operation	52

	Item Number	Average Level	Unit Value	Total Value
Raw Materials	1	1,400	$50.00	$70,000
	2	1,000	$32.00	$32,000
	3	400	$60.00	$24,000
	4	2,400	$10.00	$24,000
	5	800	$15.00	$12,000
Work in Process	6	320	$700.00	$224,000
	7	160	$900.00	$144,000
	8	280	$750.00	$210,000
	9	240	$800.00	$192,000
	10	400	$1,000.00	$400,000
Finished Goods	11	60	$2,000.00	$120,000
	12	40	$3,500.00	$140,000
	13	50	$2,800.00	$140,000
	14	20	$5,000.00	$100,000
	15	40	$4,200.00	$168,000
Total				$2,000,000

Average Weekly Sales at Cost	$192,308
Weeks of Supply	10.4
Inventory Turnover	5.0

◀ **FIGURE 12.5**
Calculating Inventory Measures Using *Inventory Estimator* Solver

SOLUTION

The average aggregate inventory value of $2 million translates into 10.4 weeks of supply and five turns per year, calculated as follows:

$$\text{Weeks of supply} = \frac{\$2\text{ million}}{(\$10\text{ million})/(52\text{ weeks})} = 10.4\text{ weeks}$$

$$\text{Inventory turns} = \frac{\$10\text{ million}}{\$2\text{ million}} = 5\text{ turns/year}$$

DECISION POINT

The analysis indicates that management must improve the inventory turns by 20 percent. Management should improve its order fulfillment process to reduce finished goods inventory. Supply chain operations can also be improved to reduce the need to have so much raw materials and work-in-process inventory stock. It will take an inventory reduction of about 16 percent to achieve the target of six turns per year. However, inventories would not have to be reduced as much if sales increased. If the sales department targets an increase in sales of 8 percent ($10.8 million), inventories need only be reduced by 10 percent ($1.8 million) to get six turns a year. Management can now do sensitivity analyses to see what effect reductions in the inventory of specific items or increases in the annual sales have on weeks of supply or inventory turns.

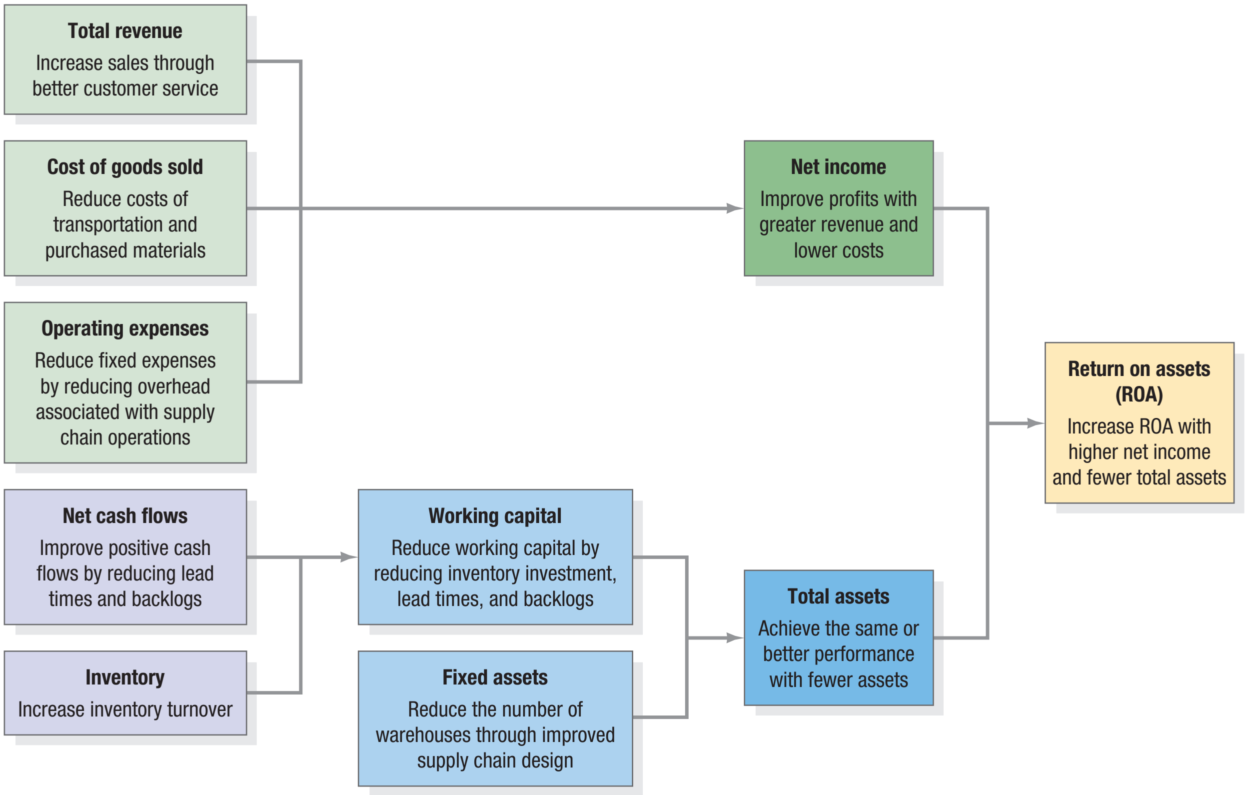
Financial Measures

How the supply chain is designed and managed has a huge financial impact on the firm. Inventory is an investment because it is needed for future use. However, inventory ties up funds that might be used more profitably in other operations. Figure 12.6 shows how supply chain decisions can affect financial measures.

Total Revenue Supply chain performance measures related to time, which is a critical dimension of supply chain operations, have financial implications. Many service providers and manufacturers measure the percent of on-time deliveries of their services or products to their customers, as well as services and materials from their suppliers. Increasing the percent of on-time deliveries to customers,

MyOMLab Animation

▼ FIGURE 12.6
How Supply Chain Decisions Can Affect ROA



for example, will increase *total revenue* because satisfied customers will buy more services and products from the firm.

Cost of Goods Sold Being able to buy materials or services at a better price and transform them more efficiently into services or products will improve a firm's *cost of goods sold* measure and ultimately its *net income*. These improvements will also have an effect on *contribution margin*, which is the difference between price and the variable costs to produce a service or good. Reducing production, material, transportation, and poor quality costs increases the contribution margin, allowing for greater profits. Contribution margins are often used as inputs to decisions regarding the portfolio of services or products the firm offers.

Operating Expenses Selling expenses, fixed expenses, and depreciation are considered operating expenses. Designing a supply chain with minimal capital investment can reduce depreciation charges. Changes to the supply chain infrastructure can have an effect on overhead, which is considered a fixed expense.

Cash Flow The supply chain design can improve positive net cash flows by focusing on reducing lead times and backlogs of orders. The Internet brings another financial measure related to cash flows to the forefront: *Cash-to-cash* is the time lag between paying for the services and materials needed to produce a service or product and receiving payment for it. The shorter the time lag, the better the *cash flow* position of the firm because it needs less working capital. The firm can then use the freed-up funds for other projects or investments. Redesigning the order placement process, so that payment for the service or product by the customer is made at the time the order is placed, can reduce the time lag. By contrast, billing the customer after the service is performed or the order is shipped increases the need for working capital. The goal is to have a negative cash-to-cash situation, which is possible when the customer pays for the service or product before the firm has to pay for the resources and materials needed to produce it. In such a case, the firm must have supplier inventories on consignment, which allows it to pay for materials as it uses them.

Working Capital Weeks of inventory and inventory turns are reflected in another financial measure, *working capital*, which is money used to finance ongoing operations. Decreasing weeks of supply or increasing inventory turns reduces the working capital needed to finance inventories. Reductions in working capital can be accomplished by improving the customer relationship, order fulfillment, or supplier relationship processes. For example, reducing supplier lead times has the effect of reducing weeks of supply and increasing inventory turns. Matching the input and output flows of materials is easier because shorter-range, more reliable forecasts of demand can be used.

Return on Assets Designing and managing the supply chain so as to reduce the aggregate inventory investment or fixed investments such as warehouses will reduce the *total assets* portion of the firm's balance sheet. An important financial measure is *return on assets* (*ROA*), which is net income divided by total assets. Consequently, reducing aggregate inventory investment and fixed investments, or increasing net income by better cost management, will increase ROA. Techniques for reducing inventory, transportation, and operating costs related to resource usage and scheduling are discussed in the chapters to follow.

We now turn to a discussion of several strategic options for supply chain design and their implications for a firm's performance.

Strategic Options for Supply Chain Design

A supply chain is, of course, a network of firms. Thus, each firm in the chain should design its own supply chains to support the competitive priorities of its services or products. Even though extensive technologies such as the Internet, computer-assisted design, flexible manufacturing, and automated warehousing have been applied to all stages of the supply chain, the performance of many supply chains remains dismal. A study of merging companies has shown that poor coordination and collaboration can drive inventory levels as much as 40 percent higher within a few months, and it can have similar effects on distribution costs, timeliness of delivery, and a variety of other metrics.[2] One possible cause for failures is that managers do not understand the nature of the demand for their services or products and, therefore, cannot design supply chains to satisfy those demands. Two distinct designs used to competitive advantage are *efficient supply chains* and *responsive supply chains*. Table 12.1 shows the environments that best suit each design.

[2]The study was conducted by the Boston Consulting Group in conjunction with Wharton University. See "Avoiding the Cost of Inefficiency: Coordination and Collaboration in Supply Chain Management," **https://knowledge.wharton.upenn.edu**, September 6, 2006.

TABLE 12.1 ENVIRONMENTS BEST SUITED FOR EFFICIENT AND RESPONSIVE SUPPLY CHAINS

Factor	Efficient Supply Chains	Responsive Supply Chains
Demand	Predictable, low forecast errors	Unpredictable, high forecast errors
Competitive priorities	Low cost, consistent quality, on-time delivery	Development speed, fast delivery times, customization, volume flexibility, variety, top quality
New-service/product introduction	Infrequent	Frequent
Contribution margins	Low	High
Product variety	Low	High

Efficient supply chains need to keep logistical costs to a minimum. Here vessels loaded with containers berth at Singapore's Keppel Port, one of the world's most efficient, and busiest, sea ports.

Roslan Rahman/AFP/Getty Images

Efficient Supply Chains

The nature of demand for the firm's services or products is a key factor in the best choice of supply chain strategy. Efficient supply chains work best in environments where demand is highly predictable, such as demand for staple items purchased at grocery stores or demand for a package delivery service.

Common Designs There is one popular design for efficient supply chains.

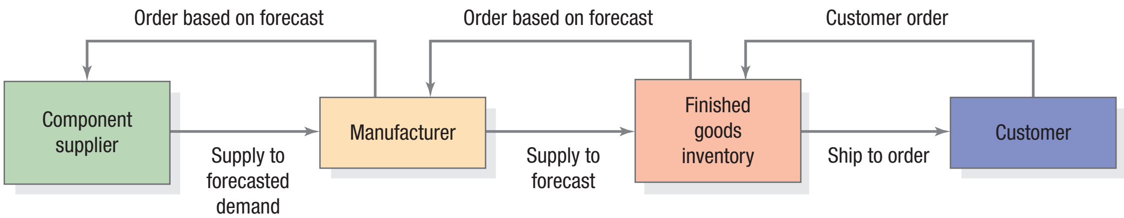
- *Make-to-stock* (MTS): The product is built to a sales forecast and sold to the customer from a finished goods stock. The end customer has no individual inputs into the configuration of the product and typically purchases the product from a retailer. Examples include groceries, books, appliances, and housewares. Figure 12.7 shows that these designs rely heavily on forecasts to move materials down the chain to the customer.

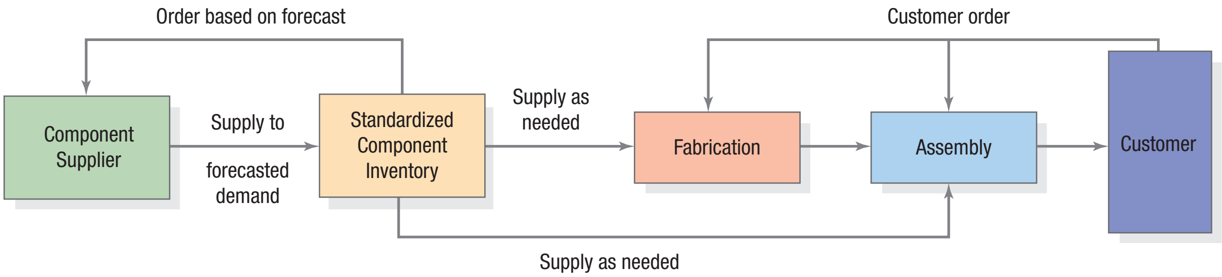
The focus of the MTS supply chain is on efficient service, material, monetary, and information flows; and keeping inventories to a minimum. Because of the markets the firms serve, service or product designs last a long time, new introductions are infrequent, and variety is small. Such firms typically produce for markets in which price is crucial to winning an order. Contribution margins are low and efficiency is important. Consequently, efficient supply chains have competitive priorities of low-cost operations, consistent quality, and on-time delivery.

Responsive Supply Chains

Responsive supply chains are designed to react quickly to hedge against uncertainties in demand. They work best when firms offer a great variety of services or products and demand predictability is low.

FIGURE 12.7 ▶
Supply Chain Design for Make-to-Stock Strategy





▲ **FIGURE 12.8**
Supply Chain Design for Assemble-to-Order Strategy

Common Designs There are three popular designs for responsive supply chains.

- *Assemble-to-order* (ATO): The product is built to customer specifications from a stock of existing components. Customers can choose among various standard components in arriving at their own products; however, they have no control over the design of the components. Assembly is delayed until the order is received. Examples include Dell's approach to customizing desktops and laptops and automobile manufacturers who offer a selection of options with each model. Figure 12.8 shows how an ATO supply chain is designed. Notice that much of the material flows are on an "as needed" basis, as opposed to the MTS design. We will return to this design when we address mass customization as a strategy.
- *Make-to-order* (MTO): The product is based on a standard design; however, component production and manufacture of the final product is linked to the customer's specifications. Examples include custom-made clothing, such as that offered by Land's End and Tommy Hilfiger, predesigned houses, and commercial aircraft, such as in the case of Boeing as depicted in Managerial Practice 12.1 (see pg. 498).
- *Design-to-order* (DTO): The product is designed and built entirely to the customer's specifications. This supply chain allows customers to design the product to fit their specific needs. Examples include large construction projects, women's designer dresses, custom-made men's suits, and original architecture house construction.

To stay competitive, firms in a responsive supply chain frequently introduce new services or products. Nonetheless, because of the innovativeness of their services or products, they enjoy high contribution margins. Typical competitive priorities for responsive supply chains are development speed, fast delivery times, customization, variety, volume flexibility, and top quality. The firms may not even know what services or products they need to provide until customers place orders. In addition, demand may be short-lived, as in the case of fashion goods. The focus of responsive supply chains is reaction time, which helps avoid keeping costly inventories that ultimately must be sold at deep discounts.

A firm may need to utilize both types of supply chains, especially when it focuses its operations on specific market segments or it can segment the supply chain to achieve two different requirements. For example, the supply chain for a standard product, such as an oil tanker, has different requirements than that for a customized product, such as a luxury liner, even though both are ocean-going vessels and both may be manufactured by the same company. You might also see elements of efficiency and responsiveness in the same supply chain. For example, Gillette uses an efficient supply chain to manufacture its products so that it can utilize a capital-intensive manufacturing process, and then it uses a responsive supply chain for the packaging and delivery processes to be responsive to retailers. The packaging operation involves customization in the form of printing in different languages. Just as processes can be broken into parts, with different process structures for each, supply chain processes can be segmented to achieve optimal performance.

Brooks Kraft/Sygma/Corbis

Gillette uses both supply chain designs: efficient and responsive. The capital-intensive processes in its Boston factory support an efficient supply chain to keep costs down. Gillette uses a responsive supply chain for packaging and delivery to service its retail customers.

Designs for Efficient and Responsive Supply Chains

Table 12.2 contains the basic design features for efficient and responsive supply chains. The more downstream in an efficient supply chain that a firm is, the more likely

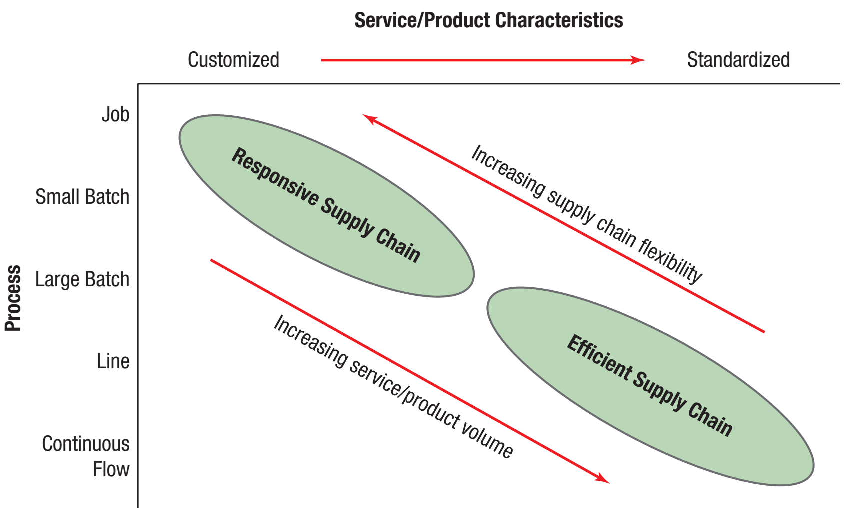
TABLE 12.2 DESIGN FEATURES FOR EFFICIENT AND RESPONSIVE SUPPLY CHAINS

Factor	Efficient Supply Chains	Responsive Supply Chains
Operation strategy	Make-to-stock standardized services or products; emphasize high volumes	Assemble-to-order, make-to-order, or design-to-order customized services or products; emphasize variety
Capacity cushion	Low	High
Inventory investment	Low; enable high inventory turns	As needed to enable fast delivery time
Lead time	Shorten, but do not increase costs	Shorten aggressively
Supplier selection	Emphasize low prices, consistent quality, on-time delivery	Emphasize fast delivery time, customization, variety, volume flexibility, top quality

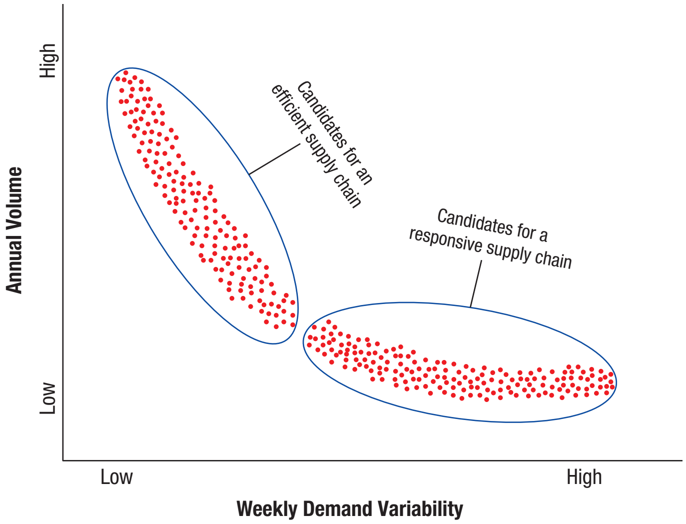
it is to have a line-flow strategy that supports high volumes of standardized services or products. Consequently, suppliers in efficient supply chains should have low capacity cushions because high utilization keeps the cost per unit low. High inventory turns are desired because inventory investment must be kept low to achieve low costs. Firms should work with their suppliers to shorten lead times, but care must be taken to use tactics that do not appreciably increase costs. For example, lead times for a supplier could be shortened by switching from rail to air transportation; however, the added cost may offset the savings or competitive advantages obtained from the shorter lead times. Suppliers should be selected with emphasis on low prices, consistent quality, and on-time delivery. Because of low capacity cushions, disruptions in an efficient supply chain can be costly and must be avoided. Figure 12.9 shows that firms with large batch, line, or continuous processes are more likely to be part of an efficient supply chain.

By contrast, firms in a responsive supply chain should be flexible and have high capacity cushions. WIP inventories should be positioned in the chain to support delivery speed, but inventories of expensive finished goods should be avoided. Firms should aggressively work with their suppliers to shorten lead times because it allows them to wait longer before committing to a customer order—in other words, it gives them greater flexibility. Firms should select suppliers to support the competitive priorities of the services or products provided, which in this case would include the ability to provide quick deliveries, customize services or components, adjust volumes quickly to match demand cycles, offer variety, and provide top quality. Figure 12.9 shows that firms with job or small batch processes are more likely to be a part of a responsive supply chain.

FIGURE 12.9 ▶
Linking Supply Chain Design to Processes and Service/Product Characteristics



Poor supply chain performance often is the result of using the wrong supply chain design for the services or products provided. A common mistake is to use an efficient supply chain in an environment that calls for a responsive supply chain. Over time, a firm may add options to its basic service or product, or introduce variations, so that the variety of its offerings increases dramatically and demand for any given service or product predictability drops. Yet the firm continues to measure the performance of its supply chain as it always has, emphasizing efficiency, even when contribution margins would allow a responsive supply chain design. Consider Figure 12.10, which shows a generalized relationship between the annual volumes of a firm's stock-keeping units (SKUs) and their weekly demand variability. For this firm, some SKUs have high volume and low variability while some SKUs have low volume and high variability. To the extent that the volatility in demands is outside the control of the firm, hanging on to the firm's legacy supply chain may be too costly because of supply chain dynamics. Mapping the portfolio of products along the dimensions of annual volume and weekly demand variability may reveal better configurations of the supply chain. A firm may therefore have two distinctly different supply chain designs serving two different product groups. For example, SKUs with lower volumes and higher weekly variability may be best served with a responsive supply chain design, such as ATO or MTO. Doing so reduces the need for finished goods inventories where customer demands are very unpredictable. Alternatively, serving the high volume, low weekly demand variability SKUs with an efficient supply chain design such as build-to-stock would be better. Forecasts are more accurate and using a finished goods inventory is an effective strategy. Redesigning a supply chain is a costly endeavor and should only be contemplated when the dynamics cannot be sufficiently reduced by other means.



▲ **FIGURE 12.10**
Annual Volume versus Variability in Weekly Demands for a Firm's SKUs

Mass Customization

A firm's supply chain must be capable of addressing certain competitive priorities that will win orders from customers. Often customers want more than a wide selection of standard services or products; they want a personalized service or product and they want it fast. For example, suppose you want to paint your living room a new color. You need to complement all of the existing furnishings, wall decorations, and carpet. You go to your local paint retail store and select a color from a stack of books that spans every color of the rainbow. The store can give you all the paint you need in your selected color while you wait. How can the store provide that service economically? Certainly the store cannot stock thousands of colors in sufficient quantities for any job. The store stocks the base colors and pigments separately and mixes them as needed, thereby supplying an unlimited variety of colors without maintaining the inventory required to match each customer's particular color needs. The paint retailer is practicing a strategy known as *mass customization*, whereby a firm's highly divergent processes generate a wide variety of customized services or products at reasonably low costs. Essentially, the firm allows customers to select from a variety of standard options to create the service or product of their choice.

Competitive Advantages

A mass customization strategy has three important competitive advantages.

- *Managing Customer Relationships.* Mass customization requires detailed inputs from customers so that the ideal service or product can be produced. The firm can learn a lot about its customers from the data it receives. Once customers are in the database, the firm can keep track of them over time. A significant competitive advantage is realized through these close customer relationships based on a strategy of mass customization.
- *Eliminating Finished Goods Inventory.* Producing to a customer's order is more efficient than producing to a forecast because forecasts are not perfect. The trick is to have everything you need to produce the order quickly. A technology some firms use for their order placement process is a software system called a *configurator*, which gives firms and customers easy access to data relevant to the options available for the service or product. Dell uses a configurator that allows customers to design their own computer from a set of standard components that are in stock. Once the order is placed, the product is assembled and then delivered. Using sales promotions, the firm can exercise some control over the requirements for the inventory of components by steering customers away from options that are out of stock in favor of options that are in stock. This capability takes pressure off the supply chain while keeping the customer satisfied.

  Service providers also take advantage of mass customization to reduce the level of inventory. British Airways is trying to personalize the service of customers once they are on board. It has a software system that tracks the preferences of its most favored customers down to the magazines they read. This information allows the airline to more accurately plan what to pack on each flight. This information saves the airline a significant amount of money because it does not pack amenities passengers do not want.
- *Increasing Perceived Value of Services or Products.* With mass customization, customers can have it their way. In general, mass customization often has a higher value in the mind of the customer than it actually costs to produce. This perception allows firms to charge prices that provide a nice margin.

Robert Gonzalez KRT/Newscom

At My Twinn doll company, kids can create their own doll online. Artisans can even match the doll face to the child's face from a photo you supply. My Twinn continues to market clothing accessories as the doll "grows up" with its human twin.

Supply Chain Design for Mass Customization

How does mass customization affect the design of supply chains? We address three major considerations.

Assemble-to-Order Strategy The underlying process design is an assemble-to-order strategy. This strategy involves two stages in the provision of the service or product. Initially, standardized components are produced or purchased and held in stock. This stage is important because it enables the firm to produce or purchase these standard items in large volumes to keep the costs low. In the second stage, the firm assembles these standard components to a specific customer order. In mass customization, this stage must be flexible to handle a large number of potential combinations and be capable of producing the order quickly and accurately. For example, for My Twinn customized dolls, customers can choose from more than 325,000 different doll combinations. To ensure accuracy, the Web site takes the customer through the required choices and allows the customer to see the doll as the various options are chosen. As shown in Figure 12.8 when we introduced the ATO design, the customer order is transmitted to the fabrication and assembly operations and standardized purchased components are taken to the point of fabrication or assembly as needed for the order. Notice that there is no finished goods inventory.

Modular Design The service or product must have a modular design that enables the "customization" the customer desires. This approach requires careful attention to service or product designs so that the final service or product can be assembled from a set of standardized modules economically and quickly in response to a customer order.

Postponement Finally, successful mass customizers postpone the task of differentiating a service or product for a specific customer until the last possible moment. *Postponement* is a concept whereby some of the final activities in the provision of a service or product are delayed until the orders are received. Doing so allows the greatest application of standard modules before specific customization is done. Postponement is a key decision because it specifies where in the supply chain volume-oriented, standardized operations are separated from custom-oriented, assembly operations. Sometimes the final customization occurs in the last step.

The assemble-to-order strategy and postponement can be extended to supply chains. The costs of inventory and transportation often determine the extent to which a manufacturer uses postponement in the supply chain. With postponement, manufacturers can avoid inventory buildup. Some firms take advantage of a process called **channel assembly**, whereby members of the distribution channel act as if they were assembly stations in the factory. Distribution centers or warehouses can perform the last-minute customizing operations after specific orders have been received. Channel assembly is particularly useful when the required customizing has some geographical rationale, such as language differences or technical requirements. In general, beyond the inventory advantages, the advantage of postponement in the distribution channel is that the firm's plants can focus on the standardized aspects of the product, while the distributor can focus on customizing a product that may require additional components from local suppliers.

channel assembly

The process of using members of the distribution channel as if they were assembly stations in the factory.

Outsourcing Processes

All businesses buy at least some inputs to their processes (such as professional services, raw materials, or manufactured parts) from other producers. Most businesses also purchase services to get their products to their customers. How many of the processes that produce those purchased items and services should a firm own and operate instead? The answer to that question determines the extent of the firm's vertical integration. The more processes in the supply chain that the organization performs itself, the more vertically integrated it is. If it does not perform some processes itself, it must rely on **outsourcing**, or paying suppliers and distributors to perform those processes and provide needed services and materials. Some firms outsource important processes such as accounting, marketing, manufacturing, or distribution. Many firms outsource payroll, security, cleaning, and other types of services rather than employ personnel to provide these services. Outsourcing is a particularly attractive option to those firms that have low volumes. What prompts a firm to outsource? An outsourcing firm realizes that another firm can perform the outsourced process more efficiently and with better quality than it can. They opt to add external suppliers to their supply chains rather than to keep internal suppliers. However, the outsourcing decision is a serious one because the firm can lose the skills and knowledge needed to conduct the process. All learning about process advancements is left to the outsourcing partner, which makes it difficult to ever bring that process back into the firm.

outsourcing
Paying suppliers and distributors to perform processes and provide needed services and materials.

The strategy of globalizing a firm adds a new dimension to the development of supply chains and the use of outsourcing. Several strategies have emerged. **Offshoring** is a supply chain strategy that involves moving processes to another country. As such, offshoring is more encompassing than outsourcing because it also includes ownership of facilities and internal processes in other countries. Firms are motivated to initiate operations offshore by the market potential and the cost advantages it provides. The firm may be able to create new markets because of its presence in other countries and its ability to offer competitive prices due to its cost efficiencies. Competitive priorities other than low costs, such as delivery speed to distant customers, can drive the decision, too. However, the term "offshoring" was popular when labor costs and other factors were very favorable in Asia and many companies were conducting operations there. Over time, costs and business conditions have changed, which has spawned sourcing strategies that focus on key operational advantages. For example, **next-shoring** is a supply chain strategy that involves locating processes in close proximity to customer demand or product R&D. These processes may be outsourced or owned by the firm and may be in-country or offshore. This strategy is useful in situations where evolving demand from new markets places a premium on the ability to adapt products to different regions or to reduce logistics costs to the new market. Other strategies, such as *near-shoring* and *on-shoring*, are largely a reaction to the increasing costs of operations and logistics in Asia and focus on moving processes closer to the home operation.

offshoring
A supply chain strategy that involves moving processes to another country.

next-shoring
A supply chain strategy that involves locating processes in close proximity to customer demand or product R&D.

Decision Factors The strategy to pursue is, of course, situational and depends on a number of factors.

- *Comparative Labor Costs.* Some countries such as China and India have traditionally held a huge edge when it comes to labor costs. In India, the salary for a computer programmer is much less than that of a programmer in the United States with comparable skills. In China, the average monthly wages are much less than those in Japan. However, the advantage of doing business in these and other low-wage countries is eroding as wages in those countries rise due to increased demands. In some cases, the labor-cost advantage may only be a short-term one because of local economic conditions, such as the lowered wage structures in the United States because of the recession of 2008.
- *Rework and Product Returns.* While labor wage rates may be low in a particular location, the quality of workmanship must also be considered. Internal rework costs and the cost of product returns may offset the advantage in wage rates.
- *Logistics Costs.* Even if labor costs are not favorable, it may still be less costly to outsource or move final assembly processes to other countries to reduce the logistical costs of delivering products to international customers. Moving processes closer to the customer and using more local suppliers reduces the cost of transporting the final product to its ultimate destination. Using shipping or air transportation can be costly because of their dependence on oil. The savings in logistical costs can offset the higher labor costs in those countries.
- *Tariffs and Taxes.* Some countries offer tax incentives to firms that do business within their borders. Tariffs can also be a stumbling block for firms looking to do business in a country. Sometimes they are high enough that the firm decides to assemble the products in that country rather than export the products in.
- *Market Effects.* Not to be overlooked is the potential advantage of next-shoring a process in a location where the presence of the firm can have a positive effect on local sales.
- *Labor Laws and Unions.* Some countries have fewer unions or restrictions on the flexible use of labor. The ability to use workers to perform a number of different tasks without restrictions can be important to firms trying to achieve flexibility in operations and reduce costs. Nonetheless, firms must be cognizant of local labor laws and customs and strive to achieve a high level of ethical behavior when doing business in other countries.
- *Internet.* The Internet reduces the transaction costs of managing distant partners or operations.
- *Energy Costs.* As technology advances and carbon-based energy sources deplete, comparative energy costs can be a major cost consideration.

Qilai Shen/In Pictures/Corbis

Employees work on the Wuling minivan engine assembly line at the SAIC GM Wuling Automobile Co., Ltd. factory in Liuzhou, Guangxi Province, China. SAIC got a license to use GM's technical knowledge for the design and manufacture of automobiles.

- *Access to Low Cost Capital.* It is often easier and cheaper to buy equipment, buildings, and land at home than it is abroad.
- *Supply Chain Complexity*. Producing goods or services in another country requires the operation of two supply chains—one at home and one in the other country. With two supply chains to manage, issues of quality, meeting customer schedule commitments, and theft of intellectual property, among other things, become real concerns.

Potential Pitfalls Even though outsourcing may appear to offer some big advantages, it also has some pitfalls that should be carefully explored before using this strategy.

- *Pulling the Plug Too Quickly.* A major mistake is to decide to outsource a process before making a good-faith effort to fix the existing one. We discussed many ways to improve processes in parts 1 and 2 of this text; these methods should be explored first. It is not always the case that outsourcing is the answer, even if local labor wages far exceed those of other countries. Make sure you really need to outsource to accomplish your operations strategy.
- *Technology Transfer.* Often an outsourcing strategy involves creating a *joint venture* with a company in another country. With a joint venture, two firms agree to jointly produce a service or product together. Typically, a transfer of technology takes place to bring one partner up to speed regarding the service or product. The danger is that the firm with the technology advantage will essentially be setting up the other firm to be a future competitor.
- *Process Integration.* Despite the power of the Internet, it is difficult to fully integrate outsourced processes with the firm's other processes. Time, distance, and communication can be formidable hurdles, especially if the supplier is on the other side of the world. Managing offshore processes will not be the same as managing processes located next door. Often considerable managerial time must be expended to coordinate offshore processes.

Managerial Practice 12.1 reveals outsourcing on a global scale can be challenging for management.

MANAGERIAL PRACTICE 12.1 Building a Supply Chain for the Dreamliner

Suppose that you had the freedom to totally design the supply chain for one of the most highly anticipated airliners of modern times. The airliner, the Boeing 787 Dreamliner, is a super-efficient commercial airplane that can carry up to 330 passengers on routes as long as 8,000 nautical miles at speeds up to 850 miles per hour. It is constructed with carbon-fiber composite materials, which are lightweight and not susceptible to corrosion or fatigue like aluminum. This plane uses 50 percent composite materials; Boeing used only 10 to 12 percent in the 777. Boeing's goal was to bring the most complex machine in mass production to market in just over 4 years, or 2 years less time than other projects. Boeing had two options for the design of the supply chain: (1) Produce about 50 percent of the plane in-house, including the wing and fuselage as in existing Boeing planes, and run the risk that production lead times will suffer because of capacity constraints; or (2) outsource about 85 percent of the plane, essentially only constructing the vertical fin in-house, and manage the global suppliers responsible for design as well as production of major components. Boeing selected option 2.

There are some good reasons for this choice. First, a number of big customers for the 787, such as India and Japan, require that significant portions of the aircraft must be manufactured in their countries. Using

AP Photo/John Froschauer

The first Boeing 787 Dreamliner takes shape in the final assembly plant in Everett, Washington. The new commercial airplane is assembled with major components produced worldwide.

major contractors within those countries satisfies the requirement. Second, a shortage of high-quality engineering talent also puts pressure on outsourcing. Third, the sheer complexity of the airplane makes it necessary to share the load. Boeing, even with all of its resources, could not build all of the components and pieces in one facility or region. Finally, work on the plane can proceed concurrently, rather than sequentially, thereby saving time and money. For example, the modular design of the plane allows Boeing to utilize flexible tooling to move planes through the factory much more quickly. The suppliers design and deliver the subsystems on a just-in-time basis where they are "snapped" together by a smaller number of factory workers in a matter of days rather than a month, the typical time for a plane of that complexity.

Boeing chose to design its supply chain with 43 top-tier suppliers on three continents. Outsourcing so much responsibility requires a lot of managerial attention; you have to know what is going on in each factory at all times. As expected with something so complex, major glitches popped up like gremlins. The first Dreamliner to show up at Boeing's factory was missing tens of thousands of parts. Supplier problems ranged from language barriers to problems caused by some contractors who outsourced major portions of their assigned work and then experienced problems with their suppliers. The first fuselage section, the big multipart cylindrical barrel that encompasses the passenger seating area, failed in company testing, causing Boeing to make more sections than planned and to reexamine quality and safety concerns. Software programs designed by a variety of manufacturers had trouble talking to one another and the overall weight of the airplane was too high, especially the carbon-fiber wing. These and many other glitches caused major delays in the promised deliveries of the first 787s. The in-service date for the first commercial 787 was October 26, 2011, more than three years behind schedule. As of May 2014, 147 of the planes have been built.

Did the advantages of collaboration on such a large scale outweigh the loss of logistical and design control? The jury is still out on that question. The latest problem involved the design of the lithium ion batteries that supply power to the energy-hungry electrical systems, which caught fire in an auxiliary power unit of a Japan Airlines 787 on the ground at Boston's Logan International Airport on January 7, 2013. The batteries have since been redesigned; however, Boeing's customers are not happy with all of the delays. Nonetheless, Boeing has more than 1,031 orders for the Dreamliner.

Source: Elizabeth Rennie, "Beyond Borders," *APICS Magazine* (March 2007), pp. 34–38; Stanley Holmes, "The 787 Encounters Turbulence," *Business Week* (June 19, 2006), pp. 38–40; J. Lynn Lunsford, "Boeing Scrambles to Repair Problems with New Plane," *The Wall Street Journal* (December 7, 2007), p. A1; "Boeing 787 Dreamliner," **http://en.wikipedia.org/wiki/Boeing_787_Dreamliner** (2014); Joan Lowry and Joshua Freed, "Lithium Batteries Are Central to Boeing's 787 Woes," Associated Press (January 18, 2013).

Vertical Integration

Outsourcing is one means to acquire processes a firm lacks or is unwilling to perform. Another approach is vertical integration whereby the firm purchases the processes it needs. Vertical integration can be in two directions. **Backward integration** represents a firm's movement upstream in the supply chain toward the sources of raw materials, parts, and services through acquisitions, such as a major grocery chain investing in its own plants to produce house brands of ice cream, frozen pizza dough, and peanut butter. Backward integration has the effect of reducing the risk of supply. **Forward integration** means that the firm acquires more channels of distribution, such as its own distribution centers (warehouses) and retail stores. It can also mean that the firm goes even farther by acquiring its business customers. A firm chooses vertical integration when it has the skills, volume, and resources to hit the competitive priorities better than outsiders can. Doing the work within its organizational structure may mean better control over quality and more timely delivery, as well as taking better advantage of the firm's human resources, equipment, and space. Extensive vertical integration is generally attractive when input volumes are high because high volumes allow task specialization and greater efficiency. It is also attractive if the firm has the relevant skills and views the processes that it is integrating as particularly important to its future success. However, care must be exercised that excessive vertical integration does not lead to a loss of focus for the firm in delivering value in its core business.

backward integration

A firm's movement upstream toward the sources of raw materials, parts, and services through acquisitions.

forward integration

Acquiring more channels of distribution, such as distribution centers (warehouses) and retail stores, or even business customers.

Management must identify, cultivate, and exploit its core competencies to prevail in global competition. Recall that core competencies reflect the collective learning of the organization, especially its ability for coordinating diverse processes and integrating multiple technologies. (See Chapter 1, "Using Operations to Create Value.") They define the firm and provide its reason for existence. Management must be constantly attentive to bolstering core competencies, perhaps by looking upstream toward its suppliers and downstream toward its customers and acquiring those processes that support its core competencies—those that allow the firm to organize work and deliver value better than its competitors. To do otherwise poses a risk that the firm will lose control over critical areas of its business.

Make-or-Buy Decisions

When managers opt for more vertical integration, by definition less outsourcing occurs. These decisions are sometimes called **make-or-buy decisions**, with a *make* decision meaning more vertical integration and a *buy* decision meaning more outsourcing. After deciding what to outsource and what to do in-house, management must find ways to coordinate and integrate the various processes and suppliers involved. Example 12.2 shows how break-even analysis, which can be found in Supplement A, "Decision Making Models," can be used for the make-or-buy decision.

make-or-buy decision

A managerial choice between whether to outsource a process or do it in-house.

EXAMPLE 12.2 Using Break-Even Analysis for the Make-or-Buy Decision

MyOMLab
Active Model A.2 in MyOMLab provides additional insight on the make-or-buy decision and its extensions.

MyOMLab
Tutor A.2 in MyOMLab provides a new example to practice break-even analysis on make-or-buy decisions.

Thompson manufacturing produces industrial scales for the electronics industry. Management is considering outsourcing the shipping operation to a logistics provider experienced in the electronics industry. Thompson's annual fixed costs of the shipping operation are \$1,500,000, which includes costs of the equipment and infrastructure for the operation. The estimated variable cost of shipping the scales with the in-house operation is \$4.50 per ton-mile. If Thompson outsourced the operation to Carter Trucking, the annual fixed costs of the infrastructure and management time needed to manage the contract would be \$250,000. Carter would charge \$8.50 per ton-mile. How many ton-miles per year would Thompson need to break even on these two options?

SOLUTION

From Supplement A, "Decision Making Models," the formula for the break-even quantity yields

$$Q = \frac{F_m - F_b}{c_b - c_m}$$

$$= \frac{1{,}500{,}000 - 250{,}000}{8.50 - 4.50} = 312{,}500 \text{ ton-miles}$$

DECISION POINT

Thompson management must now assess how many ton-miles of product will likely be shipped now and in the future. If that estimate is less than 312,500 ton-miles, the best option is to outsource the operation to Carter Trucking.

LEARNING GOALS IN REVIEW

Learning Goal	Guidelines for Review	MyOMLab Resources
1 Explain the strategic importance of supply chain design.	Review Figures 12.1 and 12.2 for the big picture of supply chain strategy and design. The section "Creating an Effective Supply Chain," pp. 505–506, reveals the nature of designing supply chains that support competitive priorities and the pressures that impinge on supply chain design.	**Video**: Supply Chain Design at Crayola
2 Identify the nature of supply chains for service providers as well as for manufacturers.	See the section "Supply Chains for Services and Manufacturing," pp. 506–508, for the similarities and differences of supply chains for service providers and manufacturers.	
3 Calculate the critical supply chain measures.	"Measuring Supply Chain Performance," pp. 508–511, explains the important inventory and financial measures. Be sure to understand Example 12.1 and the Solved Problem. Use OM Explorer Solver: Financial Measures Analyzer for the Brunswick Distribution, Inc. case.	**Active Model**: A.2 **OM Explorer Solvers:** Inventory Estimator, Financial Measures Analyzer **OM Explorer Tutors**: A.1: Break-Even, Evaluating Products and Services; A.2: Break-Even Evaluating Processes; 12.1: Calculating Inventory Measures; F.4: NPV, IRR, Payback **POM for Windows**: Break-Even Analysis, Financial Analysis **Tutor Exercise**: 12.1: Calculating Inventory Measures Under Different Scenarios
4 Explain how efficient supply chains differ from responsive supply chains and the environments best suited for each type of supply chain.	Review the section "Strategic Options for Supply Chain Design," pp. 511–515. Be sure to understand Tables 12.1 and 12.2.	

Learning Goal	Guidelines for Review	MyOMLab Resources
5 Explain the strategy of mass customization and its implications for supply chain design.	The section "Mass Customization," pp. 515–516, describes the competitive advantages and the implications for supply chain design. Be sure to understand the ATO responsive supply chain design, which is the basis for the mass customization strategy.	
6 Analyze a make-or-buy decision using break-even analysis.	Outsourcing, offshoring, and next-shoring are discussed in detail in the section "Outsourcing Processes," pp. 516–520. Be sure to review Example 12.2, which uses break-even analysis for the make-or-buy decision. Managerial Practice 12.1 shows how complex the outsourcing decision can become.	

Key Equations

Measuring Supply Chain Performance

1. Average aggregate inventory value = average inventory of each SKU multiplied by its value, summed over all SKUs held in stock.

2. $$\text{Weeks of supply} = \frac{\text{Average aggregate inventory value}}{\text{Weekly sales (at cost)}}$$

3. $$\text{Inventory turnover} = \frac{\text{Annual sales (at cost)}}{\text{Average aggregate inventory value}}$$

Outsourcing Processes

4. Make-or-buy break-even quantity: $Q = \dfrac{F_m - F_b}{c_b - c_m}$

Key Terms

average aggregate inventory value 508
backward integration 519
channel assembly 516
forward integration 519
inventory turnover 508
make-or-buy decision 519
next-shoring 517
offshoring 517
outsourcing 517
supply chain design 506
weeks of supply 508

Solved Problem

MyOMLab Video

A firm's cost of goods sold last year was $3,410,000, and the firm operates 52 weeks per year. It carries seven items in inventory: three raw materials, two work-in-process items, and two finished goods. The following table contains last year's average inventory level for each item, along with its value.

a. What is the average aggregate inventory value?

b. How many weeks of supply does the firm maintain?

c. What was the inventory turnover last year?

Category	Part Number	Average Level	Unit Value
Raw materials	1	15,000	$3.00
	2	2,500	5.00
	3	3,000	1.00
Work-in-process	4	5,000	14.00
	5	4,000	18.00
Finished goods	6	2,000	48.00
	7	1,000	62.00

SOLUTION

a.

Part Number	Average Level		Unit Value		Total Value
1	15,000	×	\$3.00	=	\$ 45,000
2	2,500	×	5.00	=	12,500
3	3,000	×	1.00	=	3,000
4	5,000	×	14.00	=	70,000
5	4,000	×	18.00	=	72,000
6	2,000	×	48.00	=	96,000
7	1,000	×	62.00	=	62,000
	Average aggregate inventory value			=	\$360,500

b. Average weekly sales at cost $= \$3{,}410{,}000/52 \text{ weeks} = \$65{,}577/\text{week}$

$$\text{Weeks of supply} = \frac{\text{Average aggregate inventory value}}{\text{Weekly sales (at cost)}} = \frac{\$360{,}500}{\$65{,}577} = 5.5 \text{ weeks}$$

c. $$\text{Inventory turnover} = \frac{\text{Annual sales (at cost)}}{\text{Average aggregate inventory value}} = \frac{\$3{,}410{,}000}{\$360{,}500} = 9.5 \text{ turns}$$

Discussion Questions

1. Explain how a firm can reduce costs while improving the performance of its supply chain.
2. Amazon.com illustrates how a new player in the retail business can overtake established organizations by focusing exclusively on online retail and strategically placing fulfillment centers across a country, in order to establish low and consistent delivery speeds. The size and setup of these fulfillment centers need to accommodate many products. Explain the strategic importance of Amazon.com's supply chain design. Focus on customization and low-cost design.
3. The Boeing 787 Dreamliner illustrates the conundrum faced when designing its supply chain. Shortage of high quality engineers prevents it from outsourcing certain components. This affects the sales as some countries will only buy aircrafts if components are outsourced. Once the make-or-buy decisions are made, taking into account these constraints and opportunities, the supply chain can be designed. Using outsourcing and vertical integration concepts discussed in this chapter, explain the choices made by Boeing to organize its supply chain for the 787 Dreamliner.

Problems

The OM Explorer and POM for Windows software is available to all students using the 11th edition of this textbook. Go to **http://www.pearsonglobaleditions.com/krajewski** to download these computer packages. If you purchased MyOMLab, you also have access to Active Models software and significant help in doing the following problems. Check with your instructor on how best to use these resources. In many cases, the instructor wants you to understand how to do the calculations by hand. At the least, the software provides a check on your calculations. When calculations are particularly complex and the goal is interpreting the results in making decisions, the software replaces entirely the manual calculations.

Measuring Supply Chain Performance

1. EBI Solar uses a high-tech process to turn silicon wafers into tiny solar panels. These efficient and inexpensive panels are used to power low-energy, hand-held electronic devices. Last year, EBI Solar turned their inventory 3.7 times and had a cost of goods sold of \$2.8 million. Assuming 52 business weeks per year:
   - **a.** Express last year's average inventory in weeks of supply.
   - **b.** After several supply chain improvement initiatives, inventory investment has dropped across all inventory categories. While EBI's cost of goods sold is not expected

to change from last year's level, the value of raw materials has dropped to \$105,000; work-in-process to \$26,000; and finished goods to \$15,800. Assuming 52 business weeks per year, express EBI's current total inventory level in weeks of supply and inventory turns.

2. Cyberphone, a manufacturer of cell phone accessories, ended the current year with annual sales (at cost) of \$48 million. During the year, the inventory of accessories turned over six times. For the next year, Cyberphone plans to increase annual sales (at cost) by 25 percent.
   a. What is the increase in the average aggregate inventory value required if Cyberphone maintains the same inventory turnover during the next year?
   b. What change in inventory turns must Cyberphone achieve if, through better supply chain management, it wants to support next year's sales with no increase in the average aggregate inventory value?
3. Jack Jones, the materials manager at Precision Enterprises, is beginning to look for ways to reduce inventories. A recent accounting statement shows the following inventory investment by category: raw materials, \$3,426,300; work-in-process, \$7,098,000; and finished goods, \$2,644,000. This year's cost of goods sold will be about \$19,864,000. Assuming 52 business weeks per year, express total inventory as
   a. Weeks of supply
   b. Inventory turns
4. One product line at Spearman Fishing Industries has 13 turns per year and an annual sales volume (at cost) of \$893,300. How much inventory is being held, on average?
5. The Bawl Corporation supplies alloy ball bearings to auto manufacturers. Because of its specialized manufacturing process, considerable work-in-process and raw materials are needed. The current inventory levels are \$2,200,000 and \$1,580,000, respectively. In addition, finished goods inventory is \$1,370,000 and sales (at cost) for the current year are expected to be about \$68 million. Assume that there are 52 business weeks per year, express total inventory as
   a. Weeks of supply
   b. Inventory turns
6. The following data were collected for a retailer:

Cost of goods sold	\$4,500,000
Gross profit	\$600,000
Operating costs	\$500,000
Operating profit	\$200,000
Total inventory	\$1,100,000
Fixed assets	\$750,000
Long-term debt	\$300,000

Assuming that there are 52 business weeks per year, express total inventory as
   a. Weeks of supply
   b. Inventory turns

7. D Sapphire Aerospace operates 52 weeks per year, and its cost of goods sold last year was \$6,500,000. The firm carries eight items in inventory: four raw materials, two work-in-process items, and two finished goods. Table 12.3 shows last year's average inventory levels for these items, along with their unit values.
   a. What is the average aggregate inventory value?
   b. How many weeks of supply does the firm have?
   c. What was the inventory turnover last year?

TABLE 12.3 SAPPHIRE AEROSPACE INVENTORY ITEMS

Category	Part Number	Average Inventory Units	Value per Unit
Raw materials	RM-1	20,000	\$1
	RM-2	5,000	5
	RM-3	3,000	6
	RM-4	1,000	8
Work-in-process	WIP-1	6,000	10
	WIP-2	8,000	12
Finished goods	FG-1	1,000	65
	FG-2	500	88

8. D Dogs-R-Us and K-9, Inc. are two retail stores that cater to the needs of dog owners in the greater Charleston area. There is healthy competition between these two establishments. Both operate 52 weeks a year and both sell approximately the same type and dollar value of items. Table 12.4 provides the cost of goods sold, the average inventory level, and unit value of each item sold in the two stores.
   a. Compare the two retail stores in terms of average aggregate inventory value.
   b. Compare the two retail stores in terms of weeks of supply.
   c. Compare the two retail stores in terms of inventory turnover.

D = Difficult Problem

TABLE 12.4 INVENTORY DATA FOR DOGS-R-US AND K-9, INC. STORES

	DOGS-R-US		K-9, INC.	
Cost of Goods Sold	**$560,000.00**		**$640,000.00**	
Category	**Average Inventory in Units**	**Value per Unit**	**Average Inventory in Units**	**Value per Unit**
Dog Beds	200	$55.00	140	$55.00
Dog Bones & Treats	1,200	$2.50	250	$2.50
Pet Feeders	50	$12.50	20	$12.50
Flea & Tick	350	$7.50	75	$7.50
Dog Kennels	10	$65.00	2	$65.00
Dog Pens	10	$220.00	3	$220.00
Patio Pet Doors	5	$120.00	2	$120.00
Dog Ramps	5	$150.00	2	$150.00
Pet Strollers	10	$40.00	2	$40.00
Pet Supplements	1,400	$4.50	150	$4.50
Dog Toys	250	$2.20	100	$2.20

Outsourcing Processes

9. D A large global automobile manufacturer is considering outsourcing the manufacturing of a solenoid used in the transmission of its SUVs. The company estimates that annual fixed costs of manufacturing the part in-house, which include equipment, maintenance, and management, amounts to $8.7 million. The variable costs of labor and material are $7.00 per unit. The company has an offer from a major subcontractor to produce the part for $10.50 per unit. However, the subcontractor wants the company to share in the costs of the equipment. The automobile company estimates that the total cost would be $3.5 million, which also includes management oversight for the new supply contact.

a. How many solenoids would the automobile company need per year to make the in-house option least costly?

b. What other factors, besides costs, should the automobile company consider before revising its supply chain for SUVs?

10. D Donegal Footwear is an international supplier of outdoor footwear for adventurous families. Currently, the company uses a logistical provider to provide warehouse services and handle packages destined for ground delivery. The contract calls for $9 million in annual fixed charges, which covers the provider's overhead and warehouse costs, and variable costs of $15 per package shipped. Recently, Donegal Footwear found a warehouse it could lease at a cost of $16 million per year, which includes lease costs, labor, and management oversight. Furthermore, the company found another provider who would deliver packages from the warehouse for $6.00 per package. Considering only costs, how many packages must Donegal Footwear ship to make the vertical integration into warehouse operations beneficial?

11. D At the BlueFin Bank corporate headquarters, management was discussing the potential of outsourcing the processing of credit card transactions to DataEase, an international provider of banking operational services. Processing of the transactions at BlueFin has been a costly element of the annual profit and loss statement and the continual investment in equipment to keep up to date has been draining capital reserves. Based upon initial study and negotiations, DataEase will charge $0.02 more per transaction than BlueFin's cost per transaction, and DataEase will want $12 million per year to cover equipment and overhead costs associated with the contract. BlueFin has yet to develop an estimate for the annual overhead and fixed costs associated with processing the transactions. These costs include supervision, administrative support, maintenance, equipment depreciation, and overhead. If BlueFin must process 20 million transactions per year, how high must those fixed costs be before it would pay to use DataEase?

12. D A global manufacturer of electrical switching equipment (ESE) is considering outsourcing the manufacturing of an electrical breaker used in the manufacturing of switch boards. The company estimates that the annual fixed cost of manufacturing the part in-house, which includes equipment, maintenance, and management, amounts to $8 million. The variable cost of labor and materials are $11.00 per breaker. The company has an offer from a major subcontractor to produce the part for $16.00 per breaker.

a. How many breakers would the electrical switching equipment company need per year to make the in-house option the least costly?

b. Assume the subcontractor wants the company to share in the costs of the equipment. The ESE company estimates that the total annual cost would be $5 million, which also includes management oversight for the new supply contract. For this concession, the subcontractor will drop the per-unit price to $12.00. Under this assumption, how many breakers would the ESE company need per year to make the in-house option least costly?

c. If the ESE manufacturer is expecting to use 1,500,000 breakers per year, which option (make in-house, use subcontractor without sharing in the cost of equipment, use subcontractor with sharing in the cost of equipment) is the least costly?

D = **Difficult Problem**

VIDEO CASE Supply Chain Design at Crayola

Crayola LLC is a profitable wholly-owned subsidiary of Hallmark Cards of Kansas City, Missouri. The company's world headquarters are located in Easton, Pennsylvania and house marketing, sales, operations & manufacturing, finance, R&D, Internet services, customer care consumer affairs and corporate communications. Sales offices in Easton, Bentonville, Arkansas, and Minneapolis manage domestic accounts, while offices in Canada, Mexico, France, Italy, Japan, and Hong Kong handle international business. The Global Operations Division in Easton is responsible for the sourcing, quality, manufacturing, and logistics of Crayola products worldwide.

Two thirds of what Crayola sells globally is produced in its three Pennsylvania facilities in the Lehigh Valley. The "Forks I" plant is devoted to manufacturing crayons and markers, the "Forks II" plant handles plastic molding, and the Lehigh Valley Industrial Park (LVIP) plant creates paints, modeling compounds, activity kits, and Silly Putty®. A single 800,000 square foot distribution center in nearby Bethlehem, Pennsylvania handles finished goods for logistics to U.S. and international customers, and to global business units.

Each plant and its products have their own unique supply chains because the raw materials, suppliers and requirements all differ. For example, paraffin wax for crayons comes from sources in Louisiana and Pennsylvania via rail tanker cars twice a week, so proximity to the railroad is essential for the Forks I plant making crayons. All raw materials for each supply chain are first evaluated by independent board-certified toxicologists so Crayola can assure its products are not only of the highest quality, but also safe and nontoxic. Then, design hazard and risk assessments are done for all products during development to assure production meets the stringent standards set by the Art and Creative Materials Institute (ACMI).

Pete Ruggiero, Executive Vice President—Global Operations and his team have responsibility for designing supply chains that are innovative, resilient, responsive, and sustainable while assuring quality, ethics and cost considerations are met. Whenever the company's marketing division develops a new product kit that might contain paints, clays, crayons, markers or other products, the supply chain sourcing of the raw materials as well as the downstream production processes must be addressed to be sure the forecasted demand can be accommodated within the existing facilities. Not long ago, the company introduced an innovative new product called ColorWonder® that consists of pens that only write on the special paper they are packed with for sale. This required examining whether the existing supply chain could support the addition of producing the specialized ink markers, where to source the coated paper, and how to best create the kits containing both markers and paper.

Now in production, ColorWonder® is a best seller worldwide, with nearly 40 percent of Japanese sales coming from this product alone. Managers received feedback from the market that the pens in the kits were lasting longer than the paper, so the supply chain responded by creating separate paper packets so consumers may purchase just the paper after the initial pages in the kit are used. The result of this action has had a ripple effect on the demand for markers, which is now lower, since consumers are buying fewer full kits but more Color Wonder® books, so the supply chain and production had to adjust once again.

Another major challenge is the assembly of kits whose components are derived from diverse supply chains and assembled into finished products in the company's LVIP plant. An example is the popular Washable Deluxe Painting Kit®. The kit consists of paints and watercolors, paint brushes, smocks for the artist, and sponges for special effects. The company wants to expand sales into the growing Asian market. The kit's paints and watercolors are made by Crayola in the U.S., but the paintbrushes come from China, the smocks come from Vietnam, and the sponges come from China. Labor costs for assembling the kits in the U.S. is a significant component, so if Crayola wants to sell the kits internationally, it needs to explore whether it makes sense to keep the existing supply chain design in place, or make a change to begin producing the kits closer to the growth in its international customer base. The lynchpin of this decision is that all components (including paint and watercolor trays historically manufactured in the United States) need to be made in Asia to make production efficient, and minimize duties and lead times. By producing the entire product—including its components and packaging—in Asia, Crayola is able to optimize its delivered cost to the markets. Producing this product in the U.S. and shipping it to Asia would be an impediment because of cost and lead time challenges.

Pearson

The Washable Deluxe Painting Kit, assembled at Crayola's Lehigh Valley Industrial Park plant, contains paints and watercolors produced in the USA and paint brushes, a smock, and a sponge produced in Asia. Demand for the kit has grown substantially in international markets, prompting a redesign of the supply chain so that Asian demand can be satisfied by Asian production facilities capable of producing and assembling the entire kit.

QUESTIONS

1. Describe the text's four external and internal pressures on supply chain design as they relate to Crayola's supply chains for ColorWonder® and Washable Deluxe Painting Kit®.
2. Review the strategic implications of supply chains as described in the text. Does Crayola have efficient or responsive supply chains, or both? Explain your position.
3. Regarding the design of the Washable Deluxe Painting Kit® supply chain, Crayola must evaluate the strategy of next-shoring in Asia or retaining an existing network that involves the assembly of the kits in the U.S. Compare and contrast these two supply chain designs from perspective of the decision factors and pitfalls for outsourcing discussed in the text.

EXPERIENTIAL LEARNING Sonic Distributors

Scenario

Sonic Distributors produces and sells music CDs. The CDs are pressed at a single facility (factory), issued through the company's distribution center, and sold to the public from various retail stores. The goal is to operate the distribution chain at the lowest total cost.

Materials (available from instructor)

Retail and distributor purchase order forms

Factory work order forms

Factory and distributor materials delivery forms

Inventory position worksheets

A means of generating random demand (typically a pair of dice)

Setup

Each team is in the business of manufacturing music CDs and distributing them to retail stores where they are sold. Two or more people play the role of retail outlet buyers. Their task is to determine the demand for the CDs and order replenishment stock from the distributor. The distributor carries forward-placed stock obtained from the factory. The factory produces in lot sizes either to customer order or to stock.

Tasks

Divide into teams of four or five.

Two or three people operate the retail stores.

One person operates the distribution center.

One person schedules production at the factory.

Every day, as play progresses, the participants at each level of the supply chain estimate demand, fill customer orders, record inventory levels, and decide how much to order or produce and when to place orders with their supplier.

Costs and Conditions

Unless your instructor indicates otherwise, the following costs and conditions hold.

Costs

Holding cost per unit per day	Retail outlets: \$1.00/CD/day
	Distribution Center: \$0.50/CD/day
	Factory: \$0.25/CD/day
Pipeline inventory cost	Assume that pipeline cost can be ignored for this exercise (consider it zero).
Ordering cost (retailers and distributors)	\$20/order
Factory setup cost (to run an order)	\$50 (Note: Cost is per order, not per day, because even though successive orders from distributors are for the same item, the factory is busy fabricating other items between orders.)
Stockout (lost margin) cost	Retail Store: \$8 per CD sale lost in a period
	\$0 for backorders for shortages from the factory or shipping new orders
Shipping cost	Because other products are already being distributed through this chain and because CDs are light and take up little volume, consider the cost to be zero.

Conditions

Starting inventory	Retail stores each have 15 CDs
	Distribution center has 25 CDs
	Factory has 100 CDs
Lot-sizing restrictions	Retail outlets and distribution centers—no minimum order. Any amount may be stored. Factory production lot sizes and capacity—produce in minimum lots of 20. Maximum capacity: 200/day.
Outstanding orders	None

Delays

Ordering Delay. One day to send an order from a retail store to the distributor or from the distributor to the factory (i.e., 1 day is lost between placing an order and the recipient acting on it).

No delay occurs in starting up production once an order has been received (but 1 day is needed for delivery of an order from the distributor to the factory).

Delivery Delay. One-day shipping time between the distributor and a retail store or between the factory and the distributor (i.e., 1 day is lost between shipping an order and receiving it).

Run the Exercise

For simplicity's sake, assume all transactions take place simultaneously at the middle of the day. For every simulated day, the sequence of play goes as follows.

Retailers

a. Each retailer receives any shipment due in from its distributor (1 day after shipment) and places it in sales inventory (adds the quantity indicated on any incoming Material Delivery Form from the distributor—after its 1-day delay—to the previous day's ending inventory level on the Retailer's Inventory Position Worksheet). (*Note:* For the first day of the exercise, no order will come in.)

b. The retailers each determine the day's retail demand (the quantity of CDs requested) by rolling a pair of dice. The roll determines the number demanded.

c. Retailers fill demand from available stock, if possible. Demand is filled by subtracting it from the current inventory level to develop the ending inventory level, which is recorded. If demand exceeds supply, sales are lost. Record all lost sales on the worksheet.

d. Retailers determine whether an order should be placed. If an order is required, the desired quantity of CDs is written on a Retail Store Purchase Order, which is forwarded to the distributor (who receives it after a 1-day delay). If an order is made, it should be noted on the worksheet. Retailers may also desire to keep track of outstanding orders separately.

Distributor

a. The distributor receives any shipment due in from the factory and places the CDs in available inventory (adds the quantity indicated on any incoming Material Delivery Form from the factory—after its 1-day delay—to the previous day's ending inventory level on the distributor's inventory position worksheet).

b. All outstanding backorders are filled (the quantity is subtracted from the current inventory level indicated on the worksheet) and prepared for shipment. CDs are shipped by filling out a Distribution Center Material Delivery Form indicating the quantity of CDs to be delivered.

c. The distributor uses the purchase orders received from the retail stores (after the designated 1-day delay) to prepare shipments for delivery from available inventory. Quantities shipped are subtracted from the current level to develop the ending inventory level, which is recorded. If insufficient supply exists, backorders are generated.

d. The distributor determines whether a replenishment order should be placed. If an order is required, the quantity of CDs is written on a Distribution Center Purchase Order, which is forwarded to the factory (after a 1-day delay). If an order is made, it should be noted on the worksheet. The distributor may also desire to keep track of outstanding orders separately.

Factory

a. The factory places any available new production into inventory (adds the items produced the previous day to the previous day's ending inventory level on the Factory Inventory Position Worksheet).

b. All outstanding backorders are filled (the quantity is subtracted from the current inventory level indicated on the worksheet) and prepared for shipment. CDs are shipped by filling out a Factory Material Delivery Form, indicating the quantity of CDs to be delivered.

c. The factory obtains the incoming distributor's purchase orders (after the designated 1-day delay) and ships them from stock, if it can. These amounts are subtracted from the current values on the inventory worksheet. Any unfilled orders become backorders for the next day.

d. The factory decides whether to issue a work order to produce CDs either to stock or to order. If production is required, a Factory Work Order is issued, and the order is noted on the inventory worksheet. Remember that a setup cost applies to each *production* order. It is important to keep careful track of all production in process.

Remember, once an order has been placed, it cannot be changed and no partial shipments can be made. For each day, record your ending inventory position, backorder or lost sales amount, and whether an order was made (or a production run initiated). After everyone completes the transactions for the day, the sequence repeats, beginning at retailer step (a). Your instructor will tell you how many simulated days to run the exercise.

When the play is stopped, find the cumulative amount of inventory and other costs. You can do so by summing up the numbers in each column and then multiplying these totals by the costs previously listed. Use the total of these costs to assess how well your team operated the distribution chain.

Source: This exercise was developed by Larry Meile, Carroll School of Management, Boston College. Reprinted by permission.

CASE Brunswick Distribution, Inc.

Alex Brunswick, CEO of Brunswick Distribution, Inc. (BDI), looked out his office window at another sweltering day and wondered what could have gone wrong at his company. He had just finished reviewing his company's recent financial performance and noticed something that worried him. BDI had experienced a period of robust growth over the last 4 years. "What could be going wrong?" he thought to himself. "Our sales have been growing at an average rate of 8 percent over the last 4 years but we still appear to be worse off than before." He sat back in his chair with a heavy sigh and continued reviewing the report on his desk.

Sales had risen consistently over the past 4 years but the future was uncertain. Alex Brunswick was aware that part of the past growth had largely been the result of a few competitors in the region going out of business, a situation that was unlikely to continue. Net earnings, however, had been declining for the last 3 years and were expected to decline next year.

Brunswick was determined to turn his company around within the next 3 years. He sat back from his desk and buzzed his personal assistant: "Gabrielle, could you ask Marianna and Bradley to come up?"

Background

The distribution business, in its simplest form, involves the purchase of inventory from a variety of manufacturers and its resale to retailers. Over the last 3 to 5 years, demands on inventory changed considerably; neither manufacturers nor retailers want to handle inventory, leaving distributors to pick up the slack. In addition, an increased tendency of retailers to order directly from manufacturers placed further strain on the profitability of distributorships in general.

After humble beginnings in a shed behind the house of Brunswick's grandmother, the company moved to a 10,000 square-foot leased facility. Ten years ago, BDI began distributing high-end appliance products to supplement its low-margin products. BDI entered into an agreement with KitchenHelper Corp., a large manufacturer of high-end kitchen appliances, located 35 miles from Moline, Illinois, to distribute KitchenHelper appliances to customers in the region. Over the years BDI enjoyed steady growth and expanded its area of coverage. Currently, Brunswick was covering an area with a radius of 200 miles from the company's main facility. Given the rapid growth, BDI purchased the leased facility and made additions to bring its capacity to 30,000 square feet.

The demise of several of its competitors resulted in the acquisition of new retailer customers and some new product lines. Traditional ordering in the retailer-distributor-manufacturer chain took place via fax or telephone. Brunswick considered implementing an Internet-based ordering system but was unsure of the potential operational and marketing benefits that it could provide.

Concerns

Market

Direct competition from distributors increased over the past 5 years. As a result, the most successful distributors adopted a value-added strategy to remain competitive. Retailers want dependable delivery to support sales promotions and promises to customers. They also want the freedom to hold sales promotions at any time as competitive conditions dictate and with only short notice to distributors. They also want the opportunity to choose from a wide variety of appliances. Nonetheless, many orders are won on the basis of price and lost on the basis of delivery problems.

Financial

Manufacturers commonly demand payment in 30 to 45 days and provide no financing considerations. Retailers, on the other hand, pay in 50 to 60 days. This difference often leaves BDI in a cash-poor situation that puts an unnecessary strain on its current operating loan. The company's borrowing capacity has almost been exhausted. Any additional financing will have to be sought from alternative sources. Given BDI's financial situation, any additional financing will be issued at a higher charge than the company's existing debt.

Operations

Inventory turnover also presented a problem for the past 5 years. In the past 2 years, however, a significant downturn in turnover occurred. This trend seems likely to continue.

Orders from retailers come in as their customers near completion of construction or renovations. Even though historical information provided a good benchmark of future sales, the changing market lessened the reliability of the information. The changes also affect BDI's ordering. Manufacturers require projections 60, 90, and 120 days out to budget their production. Sometimes penalties are assessed when BDI changes an order after it is placed with a manufacturer.

Strategic Issues

As Marianna and Bradley walked into Brunswick's office, he was still pondering the report. "Grab a seat," he grunted. They knew they were going to have a long day. Brunswick quickly briefed them on why he had summoned them, and they all immediately dove into a spirited discussion. Brunswick pointed out that BDI would need to be properly structured to deal with the recession and the reality of today's market. "We need to be well-positioned for growth as the market stabilizes," he said. To meet this challenge, BDI must evaluate a number of alternative options. Some of the possible options might include expanding current systems and, when necessary, developing new systems that interface with suppliers, customers, and commercial transportation resources to gain total asset visibility.

Before making any investment decision, Brunswick reminded them that BDI would have to evaluate any new capital requirements, as well as the expected contribution to the company's bottom line and market share, that any option might provide. Exhibit 1 shows the income statement for the current year.

Investing in New Infrastructure

Bradley Pulaski, vice president of operations, said, "Since Associated Business Distribution Corp. ceased operations 4 years ago, we have been inundated with phone calls and e-mails from potential customers across the Midwest looking for an alternative to ABD's services. These requests come not only from former ABD customers, but also from potential customers that have not dealt with either ABD or us in the past. We cannot adequately service this market from our current warehouse because the customers do not want to wait for lengthy deliveries. We are currently servicing some customers in that region; however, I do not think we can keep them much longer because of delayed deliveries. To take advantage of this opportunity, we would have to construct a new storage facility to complement our already strained resources and 'forward position' inventory to shorten our delivery times to customers on short notice. We are challenged by an inadequate infrastructure far too small for our requirements. We only have the Moline warehouse at this time." The addition of new facilities would provide BDI with an opportunity for increased penetration in key industrial markets in the upper Midwest where the company has had a limited presence.

EXHIBIT 1 ▼

Company Income Statement ($000's)		
Revenue		33,074
Cost of Goods Sold		
Shipping costs	8,931	
Direct materials	5,963	
Direct labor and other	6,726	
Total	21,620	
Gross Profit		11,454
Operating Expenses		
Selling expenses	2,232	
Fixed expenses	2,641	
Depreciation	1,794	
Total	6,667	
Earnings before Interest and Taxes		4,787
	Interest expense	838
Earnings before Taxes		3,949
	Taxes @ 35%	1,382
Net Income		2,567

The financing resources for this option would be a challenge, given that BDI was approaching its credit limit with its principal bank. Additional financing from larger banks in Chicago, however, was not ruled out. It would be expensive (with current interest rates for long-term loans starting at 11 percent). According to Bradley, this option would cost $2 million for property and $10 million for plant and equipment. The new warehouse facilities would be depreciated over 20 years. The 20-year loan would be repaid with a single balloon payment at the end of the loan. With the additional infrastructure, BDI would be able to increase its annual sales by $4,426,000. In addition, delivery lead times to customers in the region would be reduced from 5 days to 2 days, which would be very competitive. Because of the added warehouse capacity, BDI could also increase the number of brands and models of appliances to better serve the retailers' needs for more variety. However, certain categories in the costs of goods sold would also increase. Total annual shipping costs, which include supplier deliveries to the warehouse as well as deliveries to the customer, would increase by $955,000. Annual materials costs (for the sold appliances) and labor costs would each increase by 6 percent. Total assets would increase from $30,170,000 to $43,551,000. This increase takes into account changes to inventory investment, which would become $7,200,000, accounts receivable, property, and plant and equipment.

Streamlining the Distribution System

Marianna Jackson, the vice president of logistics, stated, "I believe there is an opportunity to capitalize on the void left by our fallen rivals by utilizing a cost-efficient distribution system. We do not need a new facility; we can continue to serve the customers in the Midwest as best we can.

However, what we do need is an efficient distribution system. We are holding a considerable amount of stock that has not moved simply because of our inefficient inventory systems. One of our top priorities is working diligently with the inventory control department to keep what we need and dispose of what we do not need. This approach will allow us to use the space recovered from the unneeded items for automated warehouse equipment that will enable us to become more efficient. Everything we do and every dollar we spend affects our customers. We need to keep our prices competitive. Our cost of operations is our customers' cost. Our goal is to enable customers to spend their resources on readiness and the tools of their trade, not logistics. This option will not help us much with product variety or delivery speed; however, it will increase our on-time delivery performance and improve our flexibility to respond to changes in retailer orders to support their sales programs."

The option of having an integrated center, comprised of sophisticated automation systems, advanced materials handling equipment, and specially developed information technology, would provide BDI with both the versatility and capacity to offer improved products and services to Brunswick's customers. The system would support real-time ordering, logistics planning and scheduling, and after-sales service. When an order is received through a call center at Brunswick's offices in Moline, it will be forwarded to a logistics center for processing. The customer is given a delivery date based on truck availability. Orders would be grouped by destination so that trucks could be efficiently loaded to maximize the truck capacity. The order would then be scheduled for delivery and the customer notified of the estimated arrival. This new information technology would improve BDI's reliability in delivering the products when promised. The system also includes an automatic storage and retrieval system (AS/RS). The AS/RS selects a customer order and moves it to a dock for loading on a truck headed for the customer's location. The capital costs for this system would be $7 million, which would be depreciated over a 10-year period. The operating costs, including training, would run at $0.5 million each year. These costs would be considered fixed expenses by Brunswick. The improved system, however, would have tremendous cost savings. Marianna estimated that the system would save up to 16 percent in shipping expenses and 16 percent in labor expenses annually. Total assets would increase from $30,170,000 to $35,932,000 to account for changes in accounts receivables and equipment. Aggregate inventories would be only $4,500,000 because of the reduced need for safety stock inventories. BDI could finance this option using a 10-year loan at a 10 percent rate of interest. The loan would be repaid with a balloon payment at the end of the loan.

These savings would come from more efficient handling of customers' orders by the call center, better planning and scheduling of shipments, and improved communication with the warehouse and the customer, resulting in a dramatic reduction in the shipping costs in the supply chain. Additional savings would result from the reduction in personnel costs; fewer operators would be required. Marianna Jackson thought that BDI could maintain its current level of service with her option while becoming much more efficient.

The Decision

Alex Brunswick pondered the two options posed by Bradley Pulaski and Marianna Jackson. Bradley's option enabled the firm to increase its revenues by serving more customers. The capital outlay was sizable, however. Marianna's option focused on serving the firm's existing customers more efficiently. The value of that option was its dramatic reduction in costs; however, it was uncertain whether BDI could hold onto its current upper Midwest customers. Brunswick realized that he could not undertake both options, given the company's current financial position. Brunswick uses a 12 percent cost of capital as the discount rate when making financial decisions. How will each option affect the firm's operational and financial performance measures, which investors watch closely? Which supply chain design option would be better for the company? Use the Solver "Financial Measures Analyzer" for your analysis.

Daniel Schnettler/dpa/picture-alliance/Newscom

Employees work on an off-road vehicle at the BMW plant in Spartanburg, SC. Due to the rising demand for sport all-terrain vehicles, the German automaker will extend its production capacity to 450,000 cars at the factory by the end of 2016.

13

SUPPLY CHAINS AND LOGISTICS

Bavarian Motor Works (BMW)

Location decisions have long-lasting effects and require careful analysis, especially if they involve offshore operations. Good offshore location decisions have two characteristics: (1) they are good for the company, and (2) they are good for the community where the new facility is located. Bavarian Motor Works (BMW), founded in 1917 and headquartered in Munich, Germany, is a manufacturer of select premium brands such as BMW, MINI, and Rolls-Royce Motor Cars in the international markets. Faced with a need to find an offshore manufacturing site, BMW ultimately decided on Spartanburg, South Carolina. Let's examine BMW's location analysis and the benefits to Spartanburg and the state of South Carolina.

Location analysis. Once a decision was made to explore offshore manufacturing sites, a "blank page" approach was used to compile a list of 250 potential worldwide plant sites. Further analysis pared the list down to 10 viable options; a plant location in the United States was preferred due to its proximity to a large market segment for BMW's automobiles; however, the selection of the plant site involved many factors that had to be analyzed prior to its construction. BMW considered the labor climate in each country, geographical requirements and constraints, and its relations with the governments of the countries in which the prospective sites were located. In terms of the labor climate, a technologically capable workforce was needed due to the complex nature of the automotive manufacturing process. Because the cost to train a single worker in the automotive industry is between $10,000 and $20,000, this factor was especially critical.

Geographical factors had to be examined because thousands of automobile parts needed to be delivered from both domestic and foreign suppliers. To keep the supply chain costs down, it was decided that the new location should have ample highway/interstate access and be reasonably close to a port from which both supplies and finished automobiles could be easily transported. Another consideration was easy access to an airport for BMW's executives traveling back and forth to its headquarters in Germany. The final location factor was government related. BMW wanted to move to a location that was "business friendly" in terms of making concessions on issues such as infrastructural improvements, tax abatements, and employee screening and education programs. The overall goal was to make the relationship between BMW and the local community as mutually beneficial as possible through a coordinated improvement effort.

After a 3 1/2-year search process that stringently evaluated the 10 viable options across these location factors, BMW finally decided to build a new 2-million-square-foot production facility in Spartanburg, South Carolina. The final decision was made based on a good match between the aforementioned selection criteria and the environment in Spartanburg. South Carolina lawmakers proved flexible and open as to how the state would address the needs set forth by BMW. For instance, they agreed to acquire the 500 acres necessary to build the plant (requiring a $25 million bond package be passed), improve the highway system around the facility (requiring $10 million), and lengthen the runway and modernize the terminal at the Spartanburg airport ($40 million expenditure). The legislature also agreed to provide tax incentives and property tax relief and to establish an employee screening and training program to ensure the right mix of workers were available. (Processing the applications alone proved to be a daunting task because more than 50,000 applications were received.) South Carolina may not have scored the highest on each decision criterion, but taken as a whole, the Spartanburg location was best for BMW.

Community benefits. This location proved to be a good one. The plant, which opened in July 1994, and its subsequent expansions represented an investment of $6.3 billion through December 2013. BMW Manufacturing Corporation in South Carolina today is part of BMW Group's global manufacturing network and currently employs over 8,000 people on site to produce the X3 and X5 Sports Activity Vehicle, the X4 Sports Activity Coupe, the X5 xDrive35d fuel-efficient vehicle, and the X6 Sports Activity Coupe at its 1,150-acre, 5-million-square-foot campus. Counting suppliers located in South Carolina, over 31,000 jobs were created in South Carolina because of this investment by BMW. South Carolina also reaped rewards in the form of business growth (BMW has 170 North American suppliers with 40 in South Carolina alone) and community improvements—a success story all around.

Source: "Manager's Journal: Why BMW Cruised into Spartanburg," *Wall Street Journal* (July 6, 1992), p. A10; "BMW Announces Its Plans for a Plant in South Carolina," *Wall Street Journal* (June 24, 1992), p. B2; P. Galuszka, "The South Shall Rise Again," *Chief Executive* (November 2004), pp. 50–54; Southern Business & Development, **http://www.sb-d.com** (June 2005); **http://www.bmwusfactory.com**, June 2014.

LEARNING GOALS *After reading this chapter, you should be able to:*

1. Identify the factors affecting location choices.
2. Find the center of gravity using the load–distance method.
3. Use financial data with break-even analysis to identify the location of a facility.
4. Determine the location of a facility in a network using the transportation method.
5. Understand the role of geographical information systems in making location decisions.
6. Explain the implications of centralized versus forward placement of inventories.
7. Use a preference matrix to evaluate proposed locations as part of a systematic location selection process.

Firms like BMW evaluate their supply chain network in its entirety when deciding where to locate a new facility. **Facility location** is the process of determining geographic sites for a firm's operations, which could include a manufacturing plant, a distribution center, and a customer service center. A **distribution center** is a warehouse or a stocking point where goods are stored for subsequent distribution to manufacturers, wholesalers, retailers, and customers. Location choices can be critically important for firms and have a profound impact on the strategic design of its supply chains. For example, they can affect the supplier relationship process. The expanding global economy gives firms greater access to suppliers around the world, many of whom can offer lower input costs or better-quality services and products. Nonetheless, when manufacturing facilities are offshored, locating far from one's suppliers can lead to higher transportation costs and coordination difficulties. The customer relationship process can also be affected by the firm's location decisions. If the customer must be physically present at the process, it is unlikely that a location will be acceptable if the time or distance between the service provider and customer is great. If, on the other hand, customer contact is more passive and impersonal or if materials or information are processed rather than people, then location may be less of an issue. Information technology and the Internet can sometimes help overcome the disadvantages related to a company's location. Still, one thing is clear: The location of a business's facilities has a significant impact on the company's operating costs, the prices it charges for services and goods, and its ability to compete in the marketplace and penetrate new customer segments.

facility location

The process of determining geographic sites for a firm's operations.

distribution center

A warehouse or stocking point where goods are stored for subsequent distribution to manufacturers, wholesalers, retailers, and customers.

Location decisions affect processes and departments throughout the organization. When locating new facilities, marketing must carefully assess how the location will appeal to customers and possibly open up new markets. Relocating all or part of an organization can significantly affect the attitudes of the firm's workforce and the organization's ability to operate effectively across departmental lines. Location also has implications for a firm's human resources department, which must be attuned to the firm's hiring and training needs. Locating new facilities or relocating existing facilities is usually costly; therefore, these decisions must be carefully evaluated by the organization's accounting and finance departments. For instance, when BMW located its manufacturing plant in South Carolina, the economic environment of the state and the monetary incentives offered by its legislators played a role in the financial payoff associated with the proposed new plant. Finally, operations also has an important stake in location decisions because the location needs to be able to meet current customer demand and provide the right amount of customer contact (for both external and internal customers). When their manufacturing plants are far away, firms like Gillette create active involvement by locating distribution centers in foreign countries where employees know the local culture and the language to offer "one face to the customer." International operations, like those of McDonald's, Starbucks, Toyota, and Walmart, introduce a new set of challenges because setting up and managing facilities and employees in foreign countries can be extremely time-consuming and difficult. Yet it is an important part of a firm's growth.

Analyzing location patterns to discover a firm's underlying strategy is fascinating. Recognizing the strategic impact location decisions have on implementing a firm's strategy and supply chain design, we first consider the qualitative factors that influence location choices and their implications across the organization. Subsequently, we examine quantitative methods for assisting in location decisions, including the use of geographical information systems (GIS) to identify market segments and how serving each segment can profitably affect the firm's location decisions. We follow these analytic techniques with a discussion of the placement of inventories in a supply chain network and end by presenting a systematic process for making location decisions taking into account both quantitative and qualitative factors.

Factors Affecting Location Decisions

Managers of both service and manufacturing organizations must weigh many factors when assessing the desirability of particular locations, including their proximity to customers and suppliers, labor costs, and transportation costs. Managers generally can disregard factors that fail to meet at least one of the following two conditions:

1. *The Factor Must Be Sensitive to Location.* In other words, managers should not consider a factor not affected by the location decision. For example, if community attitudes are uniformly good at all the locations under consideration, community attitudes should not be considered as a factor.
2. *The Factor Must Have a High Impact on the Company's Ability to Meet Its Goals.* For example, although different facilities will be located at different distances from suppliers, if the shipments from them can take place overnight and the communication with them is done via fax, e-mail, or teleconferencing, the distance is not likely to have a large impact on the firm's ability to meet its goals. It should therefore not be considered as a factor.

Managers can divide location factors into dominant and secondary factors. Dominant factors are derived from competitive priorities (cost, quality, time, and flexibility) and have a particularly strong impact on sales or costs. For example, a favorable labor climate and monetary incentives were dominant factors affecting the decision to locate the BMW plant in Spartanburg, South Carolina. Secondary factors also are important, but management may downplay or even ignore some of these secondary factors if other factors are more important.

Dominant Factors in Manufacturing

The following seven groups of factors dominate the decisions firms, including BMW, make about the location of new manufacturing plants or distribution centers. Often there is a trade-off among factors. Locating facilities in, say, a location with high labor costs might make sense if other factors such as logistics, taxes, and proximity to customers are favorable. Lowering the total costs of designing, developing, manufacturing, and distributing a product to its market becomes especially important in developing international supply chains and finding locations for plants, distribution centers, software design studios, and the like.

Favorable Labor Climate A favorable labor climate may well be the most important factor for labor-intensive firms in industries such as textiles, furniture, and consumer electronics. Labor climate is a function of wage rates, training requirements, attitudes toward work, worker productivity, and union strength. Many executives perceive weak unions or a low probability of union organizing efforts as a distinct advantage. Having a favorable climate applies not only to the workforce already on site but also to the employees that a firm hopes will transfer to or will be attracted to the new site. Boeing made a decision in 2009 to locate its assembly lines for the Dreamliner planes in Charleston, South Carolina, because of the favorable labor climate, as well as the presence of other Boeing facilities and suppliers in the area. It was a very carefully thought-out and crafted decision because there are only three sites worldwide at which commercial wide-body jets are assembled—Everett, Washington; Charleston, South Carolina; and Toulouse, France (Airbus plants). The 1.2-million-square-foot plant was formally inaugurated in June 2011 despite a complaint filed by the National Labor Relations Board on behalf of the labor unions in the state of Washington. Boeing would maintain assembly of the Dreamliner planes in both locations and actually added 2000 new jobs in Washington State to support that effort.

Proximity to Markets After determining where the demand for services and goods is greatest, management must select a location for the facility that will supply that demand. Often, locating operations offshore near the market is less expensive than manufacturing the product at home and shipping it. Locating near markets is particularly important when the final goods are bulky or heavy and *outbound* transportation rates are high. For example, manufacturers of products such as plastic pipe and heavy metals require proximity to their markets.

Impact on Environment As the focus on sustainability has increased, firms are looking to recognize the impact of the location decisions on the environment. Along with minimizing the carbon footprint of the new facility and its accompanying facilities in the supply chain, consideration must also be given to reducing overall energy costs. These and related issues are covered in greater detail in Chapter 15, "Managing Supply Chain Sustainability."

quality of life

A factor that considers the availability of good schools, recreational facilities, cultural events, and an attractive lifestyle.

Quality of Life Good schools, recreational facilities, cultural events, and an attractive lifestyle contribute to **quality of life**. This factor can make the difference in location decisions. In the United States during the past two decades, more than 50 percent of new industrial jobs went to nonurban regions. A similar shift is taking place in Japan and Europe. Reasons for this movement include high cost of living, high crime rate, and general decline in the quality of life in many large cities.

Yoshikazu Tsuno/AFP/Getty Images

In an attempt to minimize the carbon footprint in a populous location needing energy conservation, solar panels are placed on the roof top of a shopping mall as part of the smart city project at Kashiwaanoha in Kashiwa City, in suburban Tokyo, on July 7, 2014. The grandiose project includes a residential area, a hotel, and two national universities, and will incorporate an advanced energy management system.

Proximity to Suppliers and Resources Firms dependent on inputs of bulky, perishable, or heavy raw materials emphasize proximity to their suppliers and resources. In such cases, *inbound* transportation costs become a dominant factor, encouraging such firms to locate facilities near suppliers. For example, locating paper mills near forests and food-processing facilities near farms is practical. Another advantage of locating near suppliers is the ability to maintain lower inventories (see Chapter 6, "Designing Lean Systems," and Chapter 12, "Designing Effective Supply Chains").

Proximity to the Parent Company's Facilities In many companies, plants supply parts to other facilities or rely on other facilities for management and staff support. These ties require frequent communication and coordination, which can become more difficult as distance increases.

Utilities, Taxes, and Real Estate Costs Other location decision factors include utility costs (telephone, energy, and water), local and state taxes, financing incentives offered by local or state governments, relocation costs, and land costs. For example, the location of the Daimler plant in Alabama for manufacturing its "M series" vehicles, the BMW plant in South Carolina in the opening vignette, and a Toyota plant in Georgetown, Kentucky, were all attractive to these companies in part due to the incentives from local governments.

Other Factors Still other secondary factors may need to be considered, including room for expansion, construction costs, accessibility to multiple modes of transportation, the cost of shuffling people and materials between plants, insurance costs, competition from other firms for the workforce, local ordinances (such as pollution or noise control regulations), community attitudes, and many others. For global operations, firms need a good local infrastructure and local employees who are educated and have good skills. Many firms are concluding that large, centralized manufacturing facilities in low-cost countries with poorly trained workers are not sustainable. Smaller, flexible facilities located in the countries that the firm serves allow it to avoid problems related to trade barriers like tariffs and quotas and the risk that changing exchange rates will adversely affect its sales and profits.

Dominant Factors in Services

The factors mentioned for manufacturers also apply to service providers, especially those with low customer contact. For those service providers with considerable customer contact, there is another important consideration: The impact of location on sales and customer satisfaction.

critical mass

A situation whereby several competing firms clustered in one location attract more customers than the total number who would shop at the same stores at scattered locations.

T.M.O. Buildings/Alamy

The location of this Santander branch bank in Cambridge, England was carefully chosen for the amount of foot traffic on the street.

Shannon Stapleton/Reuters/Corbis

This is the scene that a customer looking for a new or used car sees along Northern Boulevard, New York. The car dealers are employing a critical mass strategy in the hope of attracting more customers.

Proximity to Customers Location is a key factor in determining how conveniently customers can carry on business with a firm. For example, few people will patronize a remotely located dry cleaner or supermarket if another is more convenient. Thus, the influence of location on revenues tends to be a dominant factor for many service providers. In addition, customer proximity by itself is not enough—the key is proximity to customers who will patronize the facility and seek its services. Being close to customers who match a firm's target market and service offerings is thus important for profitability.

Transportation Costs and Proximity to Markets For warehousing and distribution operations, transportation costs and proximity to markets are extremely important. With a warehouse nearby, many firms can hold inventory closer to the customer, thus reducing delivery time and promoting sales. For example, Invacare Corporation of Elyria, Ohio, gained a competitive edge in the distribution of home health care products by decentralizing inventory into 32 warehouses across the country. Invacare sells wheelchairs, hospital beds, and other patient aids—some of which it produces and some of which it buys from other firms—to small dealers who sell to consumers. Previously the dealers, often small mom-and-pop operations, had to wait three weeks for deliveries, which meant their cash was tied up in excess inventory. With Invacare's new distribution network, the dealers get daily deliveries of products from one source. Invacare's location strategy shows how timely delivery can be a competitive advantage.

Location of Competitors One complication related to estimating the sales potential of different locations is the impact of competitors. Management must not only consider the current location of competitors but also try to anticipate their reaction to the firm's new location. Avoiding areas where competitors are already well-established often pays off. However, in some industries, such as new-car sales showrooms and fast-food chains, locating near competitors is actually advantageous. The strategy is to create a **critical mass**, whereby several competing firms clustered in one location attract more customers than the total number who would shop at the same stores at scattered locations. Recognizing this effect, some firms use a follow-the-leader strategy when selecting new sites.

Site-Specific Factors Retailers also must consider the level of retail activity, residential density, traffic flow, and site visibility. Retail activity in the area is important because shoppers often decide on impulse to go shopping or to eat in a restaurant. Traffic flows and visibility are important because customers arrive in cars. Management considers possible traffic tie-ups, traffic volume and direction by time of day, traffic signals, intersections, and the position of traffic medians. Visibility involves distance from the street and the size of nearby buildings and signs. A high residential density increases nighttime and weekend business if the population in the area fits the firm's competitive priorities and target market segment.

Having examined trends and important factors in location, we now consider four methods useful for making location decisions based on quantitative factors. These methods are the load–distance method, break-even analysis, transportation method, and geographical information systems

Load–Distance Method

In every facility location analysis, attractive candidate locations must be identified and compared on the basis of quantitative factors. The load–distance method is one way to facilitate this step. Several location factors relate directly to distance: proximity to markets, average distance to target customers, proximity to suppliers and resources, and proximity to other company facilities. The **load–distance method** is a mathematical model used to evaluate locations based on proximity factors. This approach assumes that there is only one facility to be located, it must serve a predetermined set of nodes (customers, suppliers) in a logistic network, and it is independent of any other facility that may be in the network. The objective is to select a location that minimizes the sum of the loads from the facility to each node, multiplied by the distance the load travels. Time may be used instead of distance if so desired.

load–distance method

A mathematical model used to evaluate locations based on proximity factors.

Euclidean distance

The straight-line distance, or shortest possible path, between two points.

Distance Measures

For a rough calculation, which is all that is needed for the load–distance method, either a Euclidean or rectilinear distance measure may be used. **Euclidean distance** is the straight-line distance, or shortest possible path, between two points. To calculate this distance, we create a graph, such as the one in Figure 13.1, where we have the location of three customers that must receive shipments from a new facility located at the **red** node with coordinates (8, 12).

The scale of the graph can be in miles, or any suitable measure of distance, and the customers can be located on the graph in the same relative location they have in real life. Each customer has an (x,y) coordinate on the graph. The distance between two points, say, the location of customer i and the location of the proposed facility, is

$$d_i = \sqrt{(x_i - x^*)^2 + (y_i - y^*)^2}$$

where

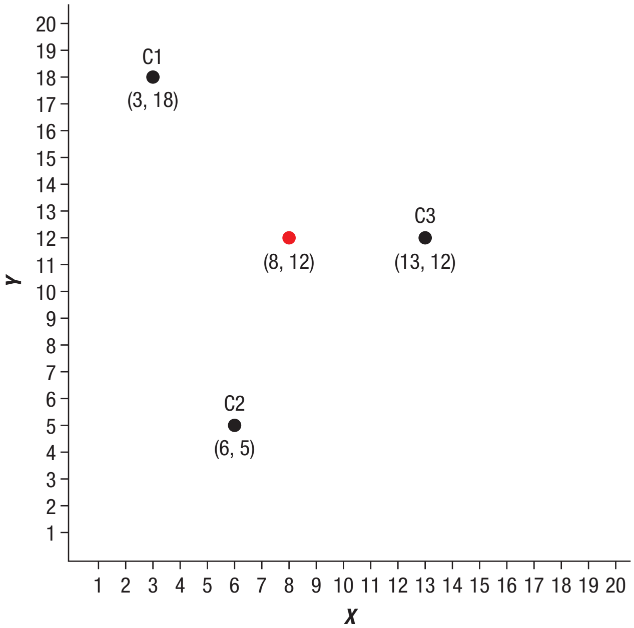
d_i = distance between customer i and the proposed facility

x_i = x-coordinate of customer i

y_i = y-coordinate of customer i

x^* = x-coordinate of proposed facility

y^* = y-coordinate of proposed facility



▲ **FIGURE 13.1**
Graph Showing Locations of Three Customers Relative to Proposed Facility

For example, suppose the unit of measurement in Figure 13.1 is miles. The Euclidean distance between Customer 1, located at (3, 18), and the proposed site, located at (8, 12), is

$$d_1 = \sqrt{(3 - 8)^2 + (18 - 12)^2} = 7.81 \text{ miles.}$$

Rectilinear distance measures the distance between two points with a series of 90-degree turns, as along city blocks. The distance traveled in the x-direction is the absolute value of the difference between the x coordinates. Adding this result to the absolute value of the difference between the y-coordinates gives

$$d_i = |x_i - x^*| + |y_i - y^*|$$

For example, the rectilinear distance between Customer 1 and the proposed site in Figure 13.1 is

$$d_1 = |3 - 8| + |18 - 12| = 11 \text{ miles.}$$

For assistance in calculating distances using either measure, see Tutor 13.1 in OM Explorer.

rectilinear distance

The distance between two points with a series of 90-degree turns, as along city blocks.

MyOMLab

Tutor 13.1 in MyOMLab provides an example to calculate both Euclidean and rectilinear distance measures.

Calculating a Load–Distance Score

Suppose that a firm seeking a new location wants to select a site that minimizes the distances that loads, particularly the larger ones, must travel to and from the site. Depending on the industry, a *load* may be shipments from suppliers, shipments between plants or to customers, or it may be customers or employees traveling to and from the facility. The firm seeks to minimize its load–distance (*ld*) score, generally by choosing a location that ensures large loads go short distances.

To calculate the *ld* score for any potential location, we could use the actual distance between any two points using a geographical information system (GIS) and simply multiply the loads flowing to and from the facility by the distances traveled. To find the lowest load–distance score with this approach would involve a lot of trial and error as each prospective location would have to be evaluated. Alternately, rectilinear or Euclidean measures can also be used as an approximation for distance using the x and y coordinates for each node in the network. The use of coordinates on a two-dimensional graph, in conjunction with a mathematical model, can be helpful in finding a good starting point for a final location. Travel time, actual miles, or Euclidean or rectilinear distances when using a graph approach, are all appropriate measures for distance. The formula for the *ld* score is

$$ld = \sum_i l_i d_i$$

where

$l_i =$ load travelling between location i and the proposed new facility.

The loads may be expressed as the number of potential customers needing physical presence at a service facility or they may be tons of product or number of trips per week for a manufacturing facility. The score is the sum of these load–distance products. By selecting a new location based on the lowest *ld* scores, customer service is improved or transportation costs reduced.

Center of Gravity

center of gravity

A good starting point to evaluate locations in the target area using the load–distance model.

Testing different locations with the load–distance model is relatively simple if some systematic search process is followed. **Center of gravity** is a good starting point to evaluate locations in the target area using the load–distance method. The first step is to determine the x and y coordinates of different locations either in the form of the longitude and latitude of the locations, or by creating a two-dimensional graph. The center of gravity's x coordinate, denoted x^*, is found by multiplying each node's x coordinate (either the longitude of the location or the x coordinate on a graph), by its load (l_i), summing these

Lynnette Peizer/Alamy

The Forks Community Hospital, located in Forks, Washington, is one of five community hospitals serving Callum County. The population of Callum County is 71,863, while the population of Forks is 3,532. The locations of the community hospitals are chosen to provide the easiest access to most citizens in the county.

products ($\sum l_i x_i$), and then dividing by the sum of the loads ($\sum l_i$). The center of gravity's y coordinate (either the latitude or the y coordinate on a grid), denoted y^*, is found the same way. The formulas are as follows:

$$x^* = \frac{\sum_i l_i x_i}{\sum_i l_i} \quad \text{and} \quad y^* = \frac{\sum_i l_i y_i}{\sum_i l_i}$$

The goal is to find one acceptable facility location that minimizes the *ld* score, where the location is defined by its x coordinate and y coordinate or the longitude and the latitude. Practical considerations rarely allow managers to select the exact location with the lowest possible score. For example, land might not be available there at a reasonable price, or other location or geographical factors may make the site undesirable. The center of gravity location generally is not the optimal one for the distance measures, but it still is an excellent starting point. The load–distance scores for locations in its vicinity can be calculated using actual distances from a GIS until the solution is near optimal.

EXAMPLE 13.1 Finding the Center of Gravity for an Electric Utilities Supplier

A supplier to the electric utility industry produces power generators; the transportation costs are high. One market area includes the lower part of the Great Lakes region and the upper portion of the southeastern region. More than 600,000 tons are to be shipped to eight major customer locations as shown below:

Customer Location	Tons Shipped	x, y Coordinates
C1: Three Rivers, MI	5,000	(7, 13)
C2: Fort Wayne, IN	92,000	(8, 12)
C3: Columbus, OH	70,000	(11, 10)
C4: Ashland, KY	35,000	(11, 7)
C5: Kingsport, TN	9,000	(12, 4)
C6: Akron, OH	227,000	(13, 11)
C7: Wheeling, WV	16,000	(14, 10)
C8: Roanoke, VA	153,000	(15, 5)

MyOMLab

Tutor 13.2 in MyOMLab provides another example on how to calculate the center of gravity.

MyOMLab

Active Model 13.1 in MyOMLab provides insight into the center of gravity method.

What is the center of gravity for the electric utilities supplier? Using rectilinear distance, what is the resulting load–distance score for this location?

SOLUTION

The center of gravity is calculated (with tons-shipped values in thousands) as shown below:

$$\sum_i l_i = 5 + 92 + 70 + 35 + 9 + 227 + 16 + 153 = 607$$

$$\sum_i l_i x_i = 5(7) + 92(8) + 70(11) + 35(11) + 9(12) + 227(13) + 16(14) + 153(15)$$

$$= 7{,}504$$

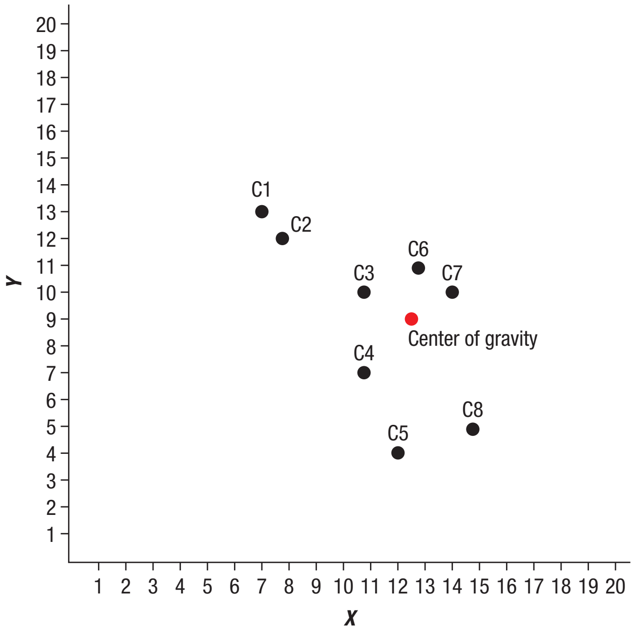
$$x^* = \frac{\sum_i l_i x_i}{\sum_i l_i} = \frac{7{,}504}{607} = 12.4$$

$$\sum_i l_i y_i = 5(13) + 92(12) + 70(10) + 35(7) + 9(4) + 227(11) + 16(10) + 153(5) = 5{,}572$$

$$y^* = \frac{\sum_i l_i y_i}{\sum_i l_i} = \frac{5{,}572}{607} = 9.2$$

Figure 13.2 shows the center of gravity location (**red**) relative to the customer locations.

FIGURE 13.2 ▶ Center of Gravity for Electric Utilities Supplier



The resulting load–distance score is

$$ld = \sum_i l_i d_i = 5(5.4 + 3.8) + 92(4.4 + 2.8) + 70(1.4 + 0.8) + 35(1.4 + 2.2) + 9(0.4 + 5.2) + 227(0.6 + 1.8) + 16(1.6 + 0.8) + 153(2.6 + 4.2)$$

$$= 2{,}662.4$$

where

$$d_i = |x_i - x^*| + |y_i - y^*|$$

DECISION POINT

The center of gravity is (12.4, 9.2) and the load–distance score is 2,662,400. Solved Problem 3 at the end of this chapter illustrates an example of using latitude and longitude rather than grid coordinates for finding the center of gravity.

Break-Even Analysis

Break-even analysis can help a manager compare location alternatives on the basis of quantitative factors that can be expressed in terms of total cost (See Supplement A, "Decision Making Models."). Given a set of potential locations for a facility, break-even analysis is particularly useful when the manager wants to define the ranges of volume over which each alternative is best. The basic steps for graphic and algebraic solutions are as follows:

1. Determine the variable costs and fixed costs for each potential site. Recall that *variable costs* are the portion of the total cost that varies directly with the volume of output. Recall that *fixed costs* are the portion of the total cost that remains constant regardless of output levels.
2. Plot the total cost lines—the sum of variable and fixed costs—for all the sites on a single graph (for assistance, see Tutors A.1 and A.2 in OM Explorer).
3. Identify the approximate ranges for which each location has the lowest cost.
4. Solve algebraically for the break-even points over the relevant ranges.

EXAMPLE 13.2 Break-Even Analysis for Location

An operations manager narrowed the search for a new facility location to four communities. The annual fixed costs (land, property taxes, insurance, equipment, and buildings) and the variable costs (labor, materials, transportation, and variable overhead) are as follows:

Community	Fixed Costs per Year	Variable Costs per Unit
A	$150,000	$62
B	$300,000	$38
C	$500,000	$24
D	$600,000	$30

MyOMLab Active Model 13.2 in MyOMLab provides insight on defining the three relevant ranges for this example.

MyOMLab Tutor 13.3 in MyOMLab provides another example to practice break-even analysis for location decisions.

Notice that no community dominates the set of alternatives; that is, no community has both the lowest fixed costs and the lowest variable costs per unit. If that were so, that community would be the best location.

Step 1. Plot the total cost curves for all the communities on a single graph. Identify on the graph the approximate volume range over which each community provides the lowest cost.

Step 2. Using break-even analysis, calculate the break-even quantities over the relevant ranges. If the expected demand is 15,000 units per year, what is the best location?

SOLUTION

Step 1. To plot a community's total cost line, let us first compute the total cost for two output levels: $Q = 0$ and $Q = 20{,}000$ units per year. For the $Q = 0$ level, the total cost is simply the fixed costs. For the $Q = 20{,}000$ level, the total cost (fixed plus variable costs) is as follows:

		VARIABLE COSTS	TOTAL COST
Community	**Fixed Costs**	**(Cost per Unit) (No. of Units)**	**(Fixed + Variable)**
A	$150,000	$62(20,000) = $1,240,000	$1,390,000
B	$300,000	$38(20,000) = $ 760,000	$1,060,000
C	$500,000	$24(20,000) = $ 480,000	$ 980,000
D	$600,000	$30(20,000) = $ 600,000	$1,200,000

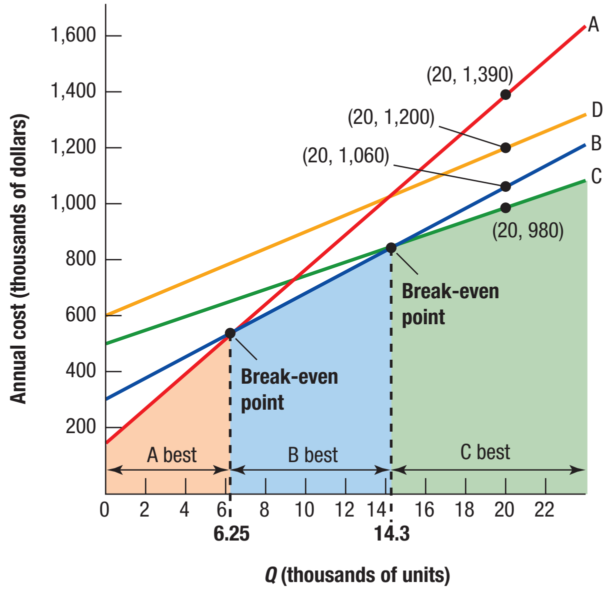
Figure 13.3 shows the graph of the total cost lines. The line for community A goes from (0, 150) to (20, 1,390). The graph indicates that community A is best for low volumes, B for intermediate volumes, and C for high volumes. We should no longer consider community D, because both its fixed *and* its variable costs are higher than community C's.

Step 2. The break-even quantity between A and B lies at the end of the first range, where A is best, and the beginning of the second range, where B is best. We find it by setting both communities' total cost equations equal to each other and solving:

(A)	(B)
$\$150{,}000 + \$62Q$	$= \$300{,}000 + \$38Q$
Q	$= 6{,}250$ units

The break-even quantity between B and C lies at the end of the range over which B is best and the beginning of the final range where C is best. It is

(B)	(C)
$\$300{,}000 + \$38Q$	$= \$500{,}000 + \$24Q$
Q	$= 14{,}286$ units



▲ **FIGURE 13.3**
Break-Even Analysis of Four Candidate Locations

No other break-even quantities are needed. The break-even point between A and C lies above the shaded area, which does not mark either the start or the end of one of the three relevant ranges.

DECISION POINT

Management located the new facility at community C, because the 15,000 units-per-year demand forecast lies in the high-volume range. These results can also be used as an input for a final decision using a preference matrix, where other non-quantitative factors could also be incorporated into the decision-making process.

Transportation Method

When a firm with a network of existing facilities plans a new facility, one of two conditions exists: (1) Either the facilities operate independently (examples include a chain of restaurants, health clinics, banks, or retail establishments) or (2) the facilities interact by moving materials or products to each other or share in the servicing of particular customers (examples include component manufacturing plants, assembly plants, and warehouses). Independently operating units can be located by treating each as a separate single facility, as we assumed with the load–distance method and break-even analysis. When facilities are interactive, the location of a new facility affects the shipping pattern of other facilities in the network. It also introduces new issues, such as how to allocate work between the facilities and how to determine the best capacity for each. Multiple-facility location problems have three dimensions—location, allocation, and capacity. Consequently, we need to use other methods to determine the best location.

transportation method for location problems

A quantitative approach that can help solve multiple-facility location problems.

Tom Bible/Alamy

Workers putting together an ultra-scanner machine at General Electric Wipro in Bangalore, India. In October, 2010, GE received a contract to supply engines for India's lightweight jetfighter and a contract from Reliance Power, Ltd. to supply turbine equipment. It also formed a joint venture with Triveni Engineering and Industries to make steam turbines as well as a healthcare joint venture with software firm Wipro. Locating such a multibusiness plant was a complex task closely akin to locating a facility in a logistic network.

The **transportation method for location problems** is a quantitative approach that can help solve multiple-facility location problems. We use it here to determine the allocation pattern that minimizes the cost of shipping products from two or more plants, or *sources of supply*, to two or more warehouses, or *destinations*. We focus on the setup and interpretation of the problem, leaving the rest of the solution process to a software package on a computer such as POM for Windows. A fuller development of this method can be found in Supplement D, "Linear Programming Models," and textbooks covering quantitative methods and management science.

The transportation method does not solve *all* facets of the multiple-facility location problem. It only finds the *best* shipping pattern between plants and warehouses for a particular set of plant locations, each with a given capacity. The analyst must try a variety of location–capacity combinations and use the transportation method to find the optimal distribution for each one. Distribution costs (variable shipping and possibly variable production costs) are but one important input in evaluating a particular location–allocation combination. Investment costs and other fixed costs also must be considered, along with various qualitative factors. This complete analysis must be made for each reasonable location–capacity combination. Because of the importance of making a good decision, this extra effort is well worth its cost.

Setting Up the Initial Tableau

The first step in solving a transportation problem is to format it in a standard matrix, sometimes called a *tableau*. The basic steps in setting up an initial tableau are as follows:

1. Create a row for each plant (existing or new) being considered and a column for each warehouse.
2. Add a column for plant capacities and a row for warehouse demands and insert their specific numerical values.
3. Each cell not in the requirements row or capacity column represents a shipping route from a plant to a warehouse. Insert the unit costs in the upper right-hand corner of each of these cells.

The Sunbelt Pool Company is considering building a new 500-unit plant because business is booming. One possible location is Atlanta. Figure 13.4 shows a tableau with its plant capacity, warehouse requirements, and shipping costs. The tableau shows, for example, that shipping one unit from the existing Phoenix plant to warehouse 1 in San Antonio, Texas, costs $5.00. Costs are assumed to increase linearly with the size of the shipment; that is, the cost is the same *per unit* regardless of the size of the total shipment.

In the transportation method, the sum of the shipments in a row must equal the corresponding plant's capacity. For example, in Figure 13.4, the total shipments from the Atlanta plant to warehouses

1, 2, and 3 located in San Antonio, Texas; Hot Springs, Arkansas; and Sioux Falls, South Dakota, respectively must add up to 500. Similarly, the sum of shipments to a column must equal the corresponding warehouse's demand requirements. Thus, shipments to warehouse 1 in San Antonio, Texas, from Phoenix and Atlanta must total 200 units.

Plant	Warehouse			Capacity
	San Antonio, TX (1)	Hot Springs, AR (2)	Sioux Falls, SD (3)	
Phoenix	5.00	6.00	5.40	400
Atlanta	7.00	4.60	6.60	500
Requirements	200	400	300	900 / 900

▲ **FIGURE 13.4**
Initial Tableau

Dummy Plants or Warehouses

The transportation method also requires that the sum of capacities equal the sum of demands, which happens to be the case at 900 units (see Figure 13.4). In many real problems, total capacity exceeds requirements, or vice versa. If capacity exceeds requirements by *r* units, we add an extra column (a *dummy warehouse*) with a demand of *r* units and make the shipping costs $0 in the newly created cells. Shipments are not actually made, so they represent unused plant capacity. Similarly, if requirements exceed capacity by *r* units, we add an extra row (a *dummy plant*) with a capacity of *r* units. We assign shipping costs equal to the stockout costs of the new cells. If stockout costs are unknown or are the same for all warehouses, we simply assign shipping costs of $0 per unit to each cell in the dummy row. The optimal solution will not be affected because the shortage of *r* units is required in all cases. Adding a dummy warehouse or dummy plant ensures that the sum of capacities equals the sum of demands. Some software packages, such as POM for Windows, automatically add them when you make the data inputs.

Finding a Solution

After the initial tableau has been set up, the goal is to find the least-cost allocation pattern that satisfies all demands and exhausts all capacities. This pattern can be found by using the transportation method, which guarantees the optimal solution. The initial tableau is filled in with a feasible solution that satisfies all warehouse demands and exhausts all plant capacities. Then a new tableau is created, defining a new solution that has a lower total cost. This iterative process continues until no improvements can be made in the current solution, signaling that the optimal solution has been found. When using a computer package, all that you have to input is the information for the initial tableau.

Another procedure is the simplex method (see Supplement D, "Linear Programming Models"), although more inputs are required. The transportation problem is actually a special case of linear programming, which can be modeled with a decision variable for each cell in the tableau, a constraint for each row in the tableau (requiring that each plant's capacity be fully utilized), and a constraint for each column in the tableau (requiring that each warehouse's demand be satisfied).

EXAMPLE 13.3 Interpreting the Optimal Solution

The optimal solution for the Sunbelt Pool Company, found with POM for Windows, is shown in Figure 13.5. Figure 13.5(a) displays the data inputs, with the cells showing the unit costs, the bottom row showing the demands, and the last column showing the supply capacities. Figure 13.5(b) shows how the existing network of plants supplies the three warehouses to minimize costs for a total of $4,580. Verify that each plant's capacity is exhausted and that each warehouse's demand is filled. Finally, Figure 13.5(c) shows the total quantity and cost of each shipment. The total optimal cost reported in the upper-left corner of Figure 13.5(b) is $4,580, or 200($5.00) + 200($5.40) + 400($4.60) + 100 ($6.60) = $4,580.

▼ **FIGURE 13.5**
POM for Windows Screens for Sunbelt Pool Company

Figure 13.5a Input Data

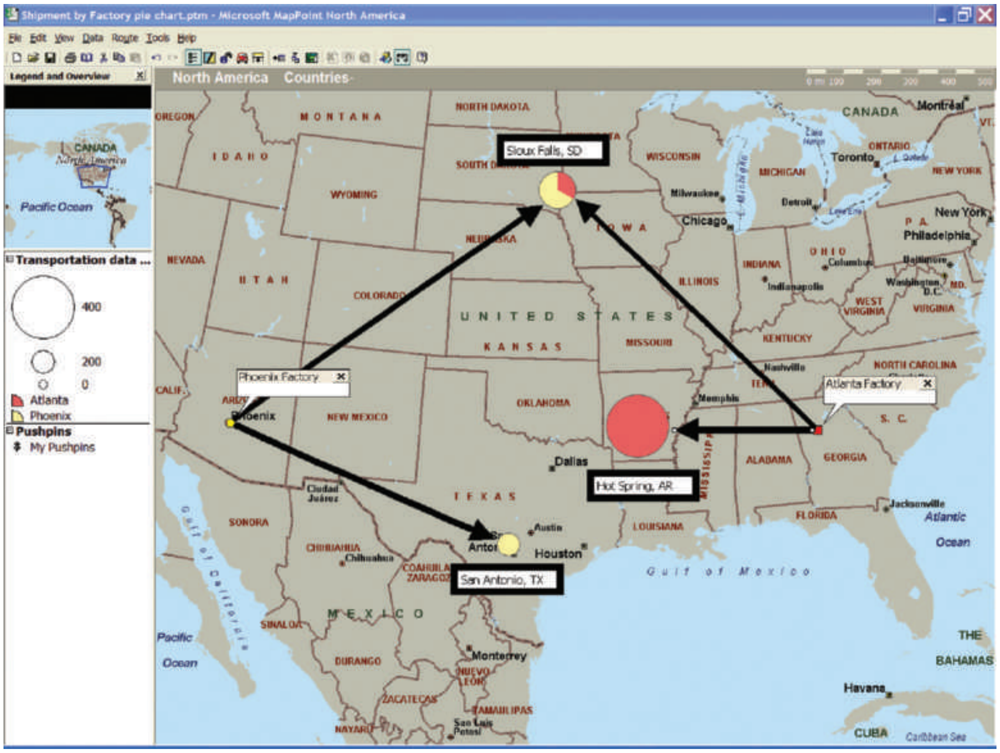
	San Antonio	Hot Springs	Sioux Falls	SUPPLY
Phoenix	5	6	5.4	400
Atlanta	7	4.6	6.6	500
DEMAND	200	400	300	

Figure 13.5b Optimal Shipping Pattern

Optimal cost = $4580	San Antonio	Hot Springs	Sioux Falls
Phoenix	200		200
Atlanta		400	100

Figure 13.5c Cost Breakdown

	San Antonio	Hot Springs	Sioux Falls
Phoenix	200/$1000		200/$1080
Atlanta		400/$1840	100/$660



▲ **FIGURE 13.6**
Optimal Transportation Solution for Sunbelt Pool Company

SOLUTION

Figure 13.6 is a map created with the MapPoint software that shows how the plants supply the three warehouses. The Phoenix plant and its shipments are represented in red and the Atlanta plant and its shipments are represented in yellow. The size of the circles for the three warehouses represents their capacities and how much of that capacity is being supplied from which plant. For example, Phoenix ships 200 units to warehouse 1 in San Antonio, Texas, and 200 units to warehouse 3 in Sioux Falls, South Dakota, exhausting its 400-unit capacity. Atlanta ships 400 units of its 500-unit capacity to warehouse 2 in Hot Springs, Arkansas, and the remaining 100 units to warehouse 3 in Sioux Falls, South Dakota. All warehouse demand is satisfied: warehouse 1 in San Antonio, Texas, is fully supplied by Phoenix and warehouse 2 in Hot Springs, Arkansas, by Atlanta. Warehouse 3 in Sioux Falls, South Dakota, receives 200 units from Phoenix and 100 units from Atlanta, satisfying its 300-unit demand. The total transportation cost is 200($5.00) + 200($5.40) + 400($4.60) + 100($6.60) = $4,580.

DECISION POINT

Management must evaluate other plant locations before deciding on the best one. The optimal solution does not necessarily mean that the best choice is to open an Atlanta plant. It just means that the best allocation pattern for the current choices on the other two dimensions of this multiple-facility location problem (that is, a capacity of 400 units at Phoenix and the new plant's location at Atlanta) results in total *transportation* costs of $4,580. The analyst should also evaluate other capacity and location combinations. For example, one possibility is to expand in Phoenix and build a smaller plant at Atlanta. Alternatively, a new plant could be built at another location, or several new plants could be built. The analyst must repeat the analysis for each such likely location strategy.

Geographical Information Systems

geographical information system (GIS)

A system of computer software, hardware, and data that the firm's personnel can use to manipulate, analyze, and present information relevant to a location decision.

A **geographical information system (GIS)** is a system of computer software, hardware, and data that the firm's personnel can use to manipulate, analyze, and present information relevant to a location decision. A GIS can also integrate different systems to create a visual representation of a firm's location choices. Among other things, it can be used to (1) store databases, (2) display maps, and (3) create models that can take information from existing datasets, apply analytic functions, and write results into newly derived datasets. Together, these three functionalities of data storage, map displays, and modeling are critical parts of an intelligent GIS and are used to a varying extent in all GIS applications.

Using GIS

A GIS can be a really useful decision-making tool because many of the decisions made by businesses today have a geographical aspect. A GIS stores information in several databases that can be naturally linked to places, such as customer sales and locations, or a census tract, or the percentage of residents in the tract that make a certain amount of money a year. The demographics of an area include the number of people in the metropolitan statistical area, city, or ZIP code; average income; number of families with children; and so forth. These demographics may all be important variables in the decision of how best to reach the target market. Similarly, the road system, including bridges and highways, the location of nearby airports and seaports, and the terrain (mountains, forests, lakes, etc.), plays an important role in

MANAGERIAL PRACTICE 13.1 How Fast-Food Chains Use GIS to Select Their Sites

Until recently, fast-food chains used consultants to analyze geodemographic data (description of different characteristics about people based upon the location where they live or work) for strategic planning and making franchise location and marketing decisions. Now with the availability of easy-to-use GISs that cost less than $5,000 and can be operated on a regular PC, small and large fast-food chains are doing it on their own. For instance, Marco's Franchising, headquartered in Toledo, Ohio, uses MapInfo's (a Windows-based mapping and geographical analysis application) GIS solutions to identify new markets where the customer and competitor landscape are best for new sites. MapInfo's Smart Site Solutions and AnySite Online technologies supply interactive mapping and reporting functionality to examine market level deployment strategies and individual site opportunities. These programs can estimate the total dollars up for grabs in a market by analyzing local age and income data from the U.S. Census Bureau as well as sales data from stores in an area—numbers that are commonly available through third-party vendors. The programs can also tell the optimal number and locations of stores in a market, and how much in sales a store can expect. Analyses can be run for any U.S. market and can rank markets in order of viability. A list of realistic sites with high sales potential can be put together at times in less than a minute. Other small fast-food chains in the United States, like Cousins Subs and 99 Restaurants and Pubs, are using in-house GIS and getting a handsome return on the investments. For instance, 99 Restaurants and Pubs found that it was able to recoup its GIS-related investment in a single week.

Bigger nationwide fast-food chains such as Domino's Pizza use GIS software to screen alternative sites for new franchises, determine how moving a store a few blocks away can affect sales, and decide when they should relocate or remodel existing stores. They can also use GIS to identify overlapping delivery zones and zones that are not being covered. Popeye's Louisiana Kitchen, Inc., which owns and franchises the Popeye's chain of restaurants, uses GIS to help it sell franchises. The level of detailed information that it can provide to prospective franchisees can make all the difference when it comes to closing the deal.

Because of its ability to provide these insights, GIS is a useful tool for expanding fast-food chains that need to quickly master the demographic details of competitive terrains in thousands of locations across the country.

Daniel Acker/Bloomberg/Getty Images

A pedestrian walks past a Domino's Pizza franchise on 89th street in New York, USA. Domino's uses GIS software to find good sites for franchises.

Source: **http://www.gis.com/whatisgis/index.html**; Ed Rubinstein, "Chains Chart Their Course of Actions with Geographic Information Systems," *Nation's Restaurant News,* vol. 32, no. 6 (1998), p. 49; "MapInfo Delivers Location Intelligence for Marco's Pizza," *Directions Magazine* (December 14, 2004), **http://www.directionsmag.com/press.releases/?duty=Show&id=10790**; Ryan Chittum, "Location, Location, and Technology: Where to Put That New Store? Site-Selection Software May Be Able to Help," *Wall Street Journal* (July 18, 2005), p. R7; **http://www.pbinsight.com/welcome/mapinfo/** (May 27, 2011).

facility location decisions. As such, a GIS can have a diverse set of location-related applications in different industries such as the retail, real estate, government, transportation, and logistics industries.

Managerial Practice 13.1 illustrates how fast-food chains use GIS to select sites. Governmental data can provide a statistical mother lode of information used to make better GIS-based location decisions. Internet sites on Yahoo!, MapQuest, and Expedia, among others, allow people to pull up maps, distances and travel times, and routes between locations, such as between Toronto, Ontario, and San Diego, California. In addition, search engines such as Google can be integrated with population demographics to create information of interest in social and business domains. Web sites are using Google maps to display high crime areas, the location of cheap gas, and apartments for rent.

Many different types of GIS packages are available, such as ArcInfo (from ESRI), MapInfo (from MapInfo), SAS/GIS (from SAS Institute, Inc.), and MapPoint (from Microsoft). Many of these systems are tailored to a specific application such as locating retail stores, redistricting legislative districts, analyzing logistics and marketing data, environmental management, and so forth. Because of its widespread availability and ease of use, MapPoint by Microsoft is an easy-to-use and fairly inexpensive GIS that mainly focuses on everyday business use by nontechnical analysts. Its ability to display information on maps can be a powerful decision-making tool especially since the maps and much of the census data comes with the software itself instead of having to be purchased separately from the GIS vendor in many other systems. MyOMLab has three videos on how MapPoint can be used to make location decisions.

MyOMLab

GIS can be useful for identifying locations that relate well to a firm's target market based on customer demographics. When coupled with other location models, sales forecasting models, and geodemographic systems, it can give a firm a formidable array of decision-making tools for its location decisions.

The GIS Method for Locating Multiple Facilities

GIS tools help visualize customer locations and data, as well as the transportation structure of roads and interstate highways. These capabilities allow the analyst to quickly arrive at a reasonable solution to the multiple-facility location problems. Load–distance score and center of gravity data can be merged with customer databases in Excel to arrive at trial locations for facilities, which can then be evaluated for annual driving time or distance using a GIS such as MapPoint and Excel. A five-step framework that captures the use of GIS for locating multiple facilities is outlined here.

1. Map the data for existing customers and facilities in the GIS.
2. Visually split the entire operating area into the number of parts or subregions that equal the number of facilities to be located.
3. Assign a facility location for each region based on the visual density of customer concentration or other factors. Alternately, determine the center of gravity for each part or subregion identified in step 2 as the starting location point for the facility in that subregion.
4. Search for alternate sites around the center of gravity to pick a feasible location that meets management's criteria such as environmental issues, availability to major metropolitan areas, or proximity to highways.
5. Compute total load–distance scores and perform capacity checks before finalizing the locations for each region.

Such an approach can have many applications, including the design of supply chain logistic networks as illustrated in the Witherspoon Automotive video in MyOMLab.

MyOMLab

Inventory Placement

centralized placement

Keeping all the inventory of a product at a single location such as at a firm's manufacturing plant or a warehouse and shipping directly to each of its customers.

inventory pooling

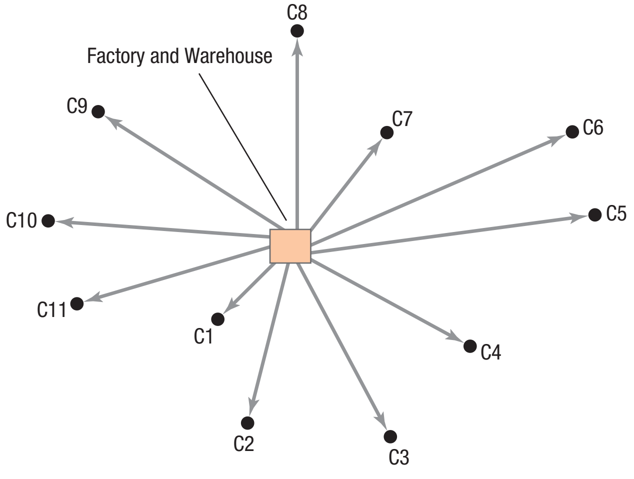
A reduction in inventory and safety stock because of the merging of variable demands from customers.

forward placement

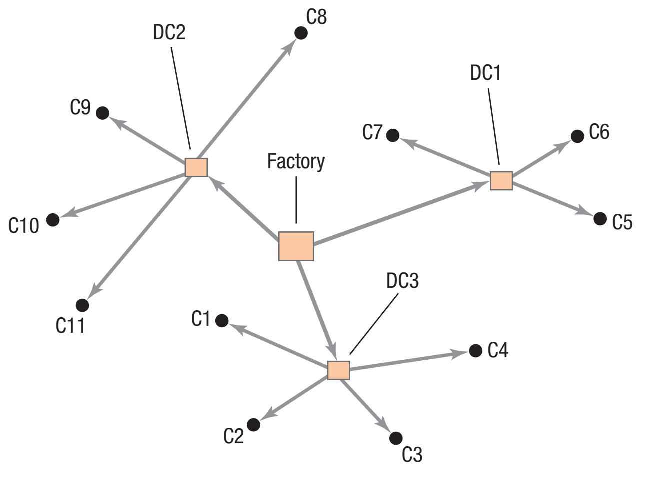
Locating stock closer to customers at a warehouse, DC, wholesaler, or retailer.

A fundamental supply chain design decision that affects performance is where to locate an inventory of finished goods. Placing inventories can have strategic implications, as in the case of international companies locating *distribution centers* (DCs) in foreign countries to preempt local competition by reducing customer delivery times. However, the issue for any firm producing standardized products is where to position the inventory in the supply chain. At one extreme, the firm could use **centralized placement**, which means keeping all the inventory of a product at a single location, such as a firm's manufacturing plant or a warehouse, and shipping directly to each of its customers. The advantage would come from what is referred to as **inventory pooling**, which is a reduction in inventory and safety stock because of the merging of uncertain and variable demands from the customers. A higher-than-expected demand from one customer can be offset by a lower-than-expected demand from another so that the total demand remains fairly stable. A disadvantage of placing inventory at a central location, however, is the added cost of shipping smaller, uneconomical quantities directly to customers over long distances. Figure 13.7 shows that centralized placement of inventories can involve considerable logistics costs.

Another approach is to use **forward placement**, which means locating stock closer to customers at a warehouse, DC, wholesaler, or retailer. Forward placement can have two advantages—faster



▲ FIGURE 13.7
Centralized Placement with Inventory Pooling



▲ FIGURE 13.8
Forward Placement of Inventories

delivery times and reduced transportation costs—that can stimulate sales. However, as inventory is placed closer to the customer, such as at a DC, the pooling effect of the inventories is reduced because safety stocks for the item must increase to take care of uncertain demands at each DC rather than just a single location. Nonetheless, the time to get the product to the customer is reduced. Consequently, service to the customer is quicker, and the firm can take advantage of larger, less costly shipments to the DCs from the manufacturing plant at the expense of larger overall inventories, as shown in Figure 13.8.

A Systematic Location Selection Process

Quantifiable costs and other measures as well as various qualitative factors must be considered as parts of a complete evaluation. For example, the impact on the environment must be balanced against the land and construction costs of a new plant. How does one proceed with a comprehensive analysis? A systematic location selection process begins after perception or evidence indicates that opening a retail outlet, warehouse, office, or plant in a new location will improve performance. The process of selecting a new facility location involves a series of steps.

1. Identify the important location factors and categorize them as dominant or secondary.
2. Consider alternative regions; then narrow the choices to alternative communities and finally to specific sites.
3. Collect data on the alternatives from location consultants, state development agencies, city and county planning departments, chambers of commerce, land developers, electric power companies, banks, and onsite visits. Some of these data and information may also be contained inside the GIS.
4. Analyze the data collected, beginning with the *quantitative* factors—factors that can be measured in dollars, such as annual transportation costs or taxes. The quantitative factors can also be measured in terms other than dollars, such as driving time and miles. These values may be broken into separate cost categories (e.g., inbound and outbound transportation, labor, construction, and utilities) and separate revenue sources (say sales, stock or bond issues, and interest income). These financial factors can then be converted to a single measure of financial merit such as total costs, return on investment (ROI), or net present value (NPV) and used to compare two or more sites, especially if capital costs for the new facility are also considered.
5. Bring the qualitative factors pertaining to each site into the evaluation. A *qualitative* factor is one that cannot be evaluated in dollar terms, such as community attitudes, environmental factors, or quality of life. To merge quantitative and qualitative factors, some managers review the expected performance of each factor, while others assign each factor a weight of relative importance and calculate a weighted score for each site using a preference matrix (see Supplement A, "Decision Making Models"). What is important in one situation may be unimportant or less important in another. The site with the highest weighted score is best. Example 13.4 shows how a preference matrix can help determine the best location.

EXAMPLE 13.4 Calculating Weighted Scores in a Preference Matrix

A new medical facility, Health-Watch, is to be located in Erie, Pennsylvania. The following table shows the location factors, weights, and scores ($1 = $ poor, $5 = $ excellent) for one potential site. The weights in this case add up to 100 percent. A weighted score (*WS*) will be calculated for each site. What is the *WS* for this site?

MyOMLab

Tutor 13.4 in MyOMLab provides another example to practice with a preference matrix for location decisions.

Location Factor	Weight	Score
Total patient miles per month	25	4
Facility utilization	20	3
Average time per emergency trip	20	3
Expressway accessibility	15	4
Land and construction costs	10	1
Employee preferences	10	5

SOLUTION

The *WS* for this particular site is calculated by multiplying each factor's weight by its score and adding the results:

$$\begin{aligned} WS &= (25 \times 4) + (20 \times 3) + (20 \times 3) + (15 \times 4) + (10 \times 1) + (10 \times 5) \\ &= 100 + 60 + 60 + 60 + 10 + 50 \\ &= 340 \end{aligned}$$

The total *WS* of 340 can be compared with the total weighted scores for other sites being evaluated.

6. After thoroughly evaluating all potential sites, those making the study prepare a final report containing site recommendations, along with a summary of the data and analyses on which they are based. An audiovisual presentation of the key findings usually is delivered to top management in large firms.

LEARNING GOALS IN REVIEW

Learning Goal	Guidelines for Review	MyOMLab Resources
1 Identify the factors affecting location choices.	See the section "Factors Affecting Location Decisions," pp. 534–537. Focus on understanding the key differences between locating manufacturing versus service facilities.	**Video:** Continental Tire: New Manufacturing Plant Decision
2 Find the center of gravity using the load–distance method.	The section "Load–Distance Method," pp. 537–540, discusses the distance measures, the load–distance metric, and the calculations for the center of gravity. Study Solved Problem 1, which shows how to use the method using longitude and latitude as coordinates.	**Active Model:** 13.1: Center of Gravity **OM Explorer Solver:** Center of Gravity **OM Explorer Tutors:** 13.1: Distance Measures; 13.2: Center of Gravity **POM for Windows:** Two-Dimensional Siting
3 Use financial data with break-even analysis to identify the location of a facility.	See the section "Break-Even Analysis," pp. 540–542, for a demonstration of how financial data can be used in selecting the location of a facility. Solved Problem 2 shows how to find the range of volumes over which each location option may be effective.	**Active Model:** 13.2: Break-Even Analysis for Location **OM Explorer Tutor:** 13.3: Break-Even Analysis for Location **OM Explorer Solver:** Break-Even Analysis **POM for Windows:** Cost-Volume Analysis
4 Determine the location of a facility in a network using the transportation method.	Review the section "Transportation Method," pp. 542–544, which shows how to use the POM for Windows software and interpret the results. Be sure to understand how to read an output from the analysis. Solved Problem 3 shows the setup, solution, and interpretation of a location problem.	**POM for Windows:** Transportation Method (Location)
5 Understand the role of geographical information systems in making location decisions.	The section "Geographical Information Systems," pp. 544–546, and Managerial Practice 13.1, show you how firms are using GIS software packages to make demographic-data-driven location decisions that are inexpensive as well as effective in simultaneously considering several location decision variables.	**MapPoint Videos:** Starbucks, Witherspoon Automotive, and Tyler EMS
6 Explain the implications of centralized versus forward placement of inventories.	See the section "Inventory Placement," pp. 546–547, and study Figure 13.7 and Figure 13.8 to understand the implications of the inventory placement decision.	
7 Use a preference matrix to evaluate proposed locations as part of a systematic location selection process.	The section "A Systematic Location Selection Process," pp. 547–548, describes a process that leads to a rational selection of a facility location given a set of alternatives. Be sure to review how a preference matrix can be used to include both qualitative and quantitative factors in the final analysis. Solved Problem 4 shows a detailed example.	**OM Explorer Tutor:** 13.4: Preference Matrix for Location **OM Explorer Solver:** Preference Matrix **POM for Windows:** Weighting Method

Key Equations

Load–Distance Method

1. Euclidean distance: $d_i = \sqrt{(x_i - x^*)^2 + (y_i - y^*)^2}$

2. Rectilinear distance: $d_i = |x_i - x^*| + |y_i - y^*|$

3. Load–distance score: $ld = \sum_i l_i d_i$

4. Center of gravity: $x^* = \dfrac{\sum_i l_i x_i}{\sum_i l_i}$ and $y^* = \dfrac{\sum_i l_i y_i}{\sum_i l_i}$

Key Terms

center of gravity 538
centralized placement 546
critical mass 536
distribution center 533
Euclidean distance 537
facility location 533
forward placement 546
geographical information system (GIS) 544
inventory pooling 546
load–distance method 537
quality of life 534
rectilinear distance 537
transportation method for location problems 542

Solved Problem 1

The new Health-Watch facility is targeted to serve seven census tracts in Erie, Pennsylvania, whose latitudes and longitudes are shown in Table 13.1, along with the population in each census tract (in thousands). Customers will travel from the seven census-tract centers to the new facility when they need health care. What is the target area's center of gravity for the Health-Watch medical facility?

TABLE 13.1 | LOCATION DATA AND CALCULATIONS FOR HEALTH-WATCH

Census Tract	Population	Latitude	Longitude	Population × Latitude	Population × Longitude
15	2,711	42.134	−80.041	114,225.27	−216,991.15
16	4,161	42.129	−80.023	175,298.77	−332,975.70
17	2,988	42.122	−80.055	125,860.54	−239,204.34
25	2,512	42.112	−80.066	105,785.34	−201,125.79
26	4,342	42.117	−80.052	182,872.01	−347,585.78
27	6,687	42.116	−80.023	281,629.69	−535,113.80
28	6,789	42.107	−80.051	285,864.42	−543,466.24
Total	**30,190**			**1,271,536.04**	**−2,416,462.80**

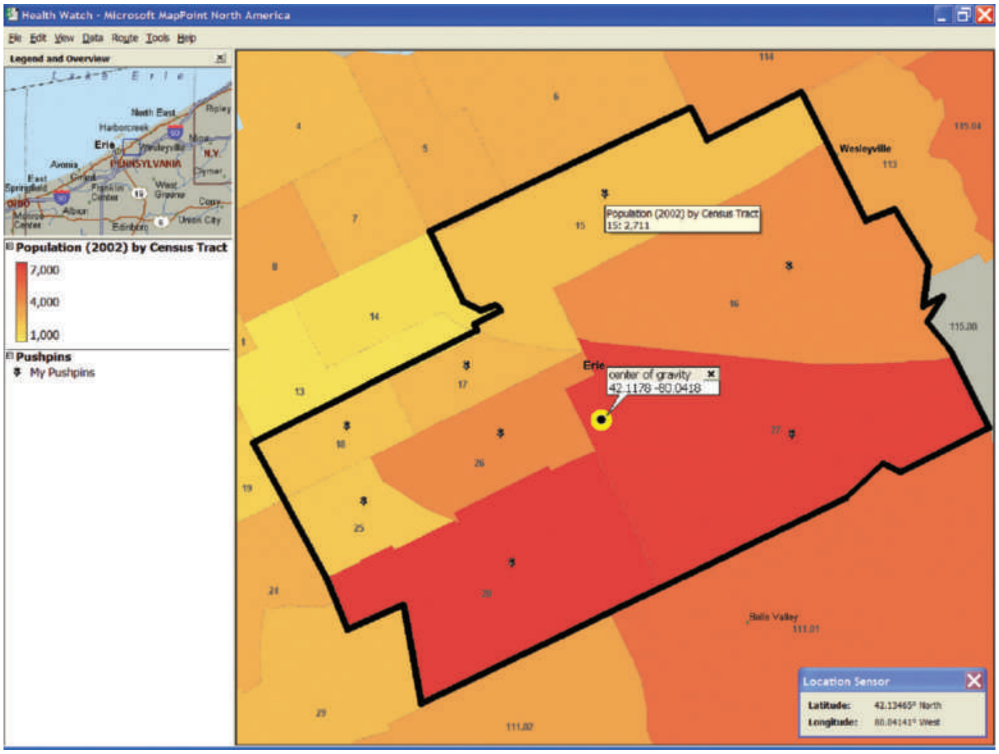
SOLUTION

We solve for the center of gravity x^* and y^*. Because the coordinates are given as longitude and latitude, x^* is the longitude and y^* is the latitude for the center of gravity.

$$x^* = \frac{1{,}271{,}536.05}{30{,}190} = 42.1178$$

$$y^* = \frac{-\ 2{,}416{,}462.81}{30{,}190} = -80.0418$$

FIGURE 13.9 ▶
Center of Gravity for Health-Watch



The center of gravity is (42.12 North, 80.04 West) and is shown in Figure 13.9 to be fairly central to the target area.

Active Model 13.1 in MyOMLab confirms these calculations for the center of gravity, and allows us to explore other alternative locations as well.

Solved Problem 2

MyOMLab Video

The operations manager for Mile-High Lemonade narrowed the search for a new facility location to seven communities. Annual fixed costs (land, property taxes, insurance, equipment, and buildings) and variable costs (labor, materials, transportation, and variable overhead) are shown in Table 13.2.

a. Which of the communities can be eliminated from further consideration because they are dominated (both variable and fixed costs are higher) by another community?

b. Plot the total cost curves for all remaining communities on a single graph. Identify on the graph the approximate range over which each community provides the lowest cost.

c. Using break-even analysis, calculate the break-even quantities to determine the range over which each community provides the lowest cost.

TABLE 13.2 | **FIXED AND VARIABLE COSTS FOR MILE-HIGH LEMONADE**

Community	Fixed Costs per Year	Variable Costs per Barrel
Aurora	$1,600,000	$17.00
Boulder	$2,000,000	$12.00
Colorado Springs	$1,500,000	$16.00
Denver	$3,000,000	$10.00
Englewood	$1,800,000	$15.00
Fort Collins	$1,200,000	$15.00
Golden	$1,700,000	$14.00

SOLUTION

a. Aurora and Colorado Springs are dominated by Fort Collins because both fixed and variable costs are higher for those communities than for Fort Collins. Englewood is dominated by Golden.

b. Figure 13.10 shows that Fort Collins is best for low volumes, Boulder for intermediate volumes, and Denver for high volumes. Although Golden is not dominated by any community, it is the second or third choice over the entire range. Golden does not become the lowest-cost choice at any volume.

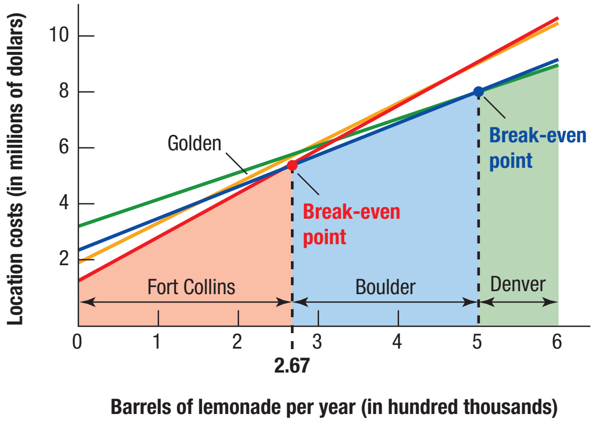


FIGURE 13.10
Break-Even Analysis for Mile-High lemonade

c. The break-even point between Fort Collins and Boulder is

$$\$1{,}200{,}000 + \$15Q = \$2{,}000{,}000 + \$12Q$$
$$Q = 266{,}667 \text{ barrels per year}$$

The break-even point between Denver and Boulder is

$$\$3{,}000{,}000 + \$10Q = \$2{,}000{,}000 + \$12Q$$
$$Q = 500{,}000 \text{ barrels per year}$$

Solved Problem 3

The Arid Company makes canoe paddles to serve distribution centers in Worchester, Rochester, and Dorchester from existing plants in Battle Creek and Cherry Creek. Arid is considering locating a plant near the headwaters of Dee Creek. Annual capacity for each plant is shown in the right-hand column, while annual demand is shown in the bottom row of the tableau in Figure 13.11. Transportation costs per paddle are shown in the tableau in the small boxes. For example, the cost to ship one paddle from Battle Creek to Worchester is \$4.37. The optimal allocations using the transportation method for location problems are also shown in Figure 13.11. For example, Battle Creek ships 12,000 units to Rochester. What are the estimated transportation costs associated with this allocation pattern?

Source	Destination			Capacity
	Worchester	Rochester	Dorchester	
Battle Creek	\$4.37	\$4.25 **12,000**	\$4.89	12,000
Cherry Creek	\$4.00 **6,000**	\$5.00 **4,000**	\$5.27	10,000
Dee Creek	\$4.13	\$4.50 **6,000**	\$3.75 **12,000**	18,000
Demand	6,000	22,000	12,000	40,000

FIGURE 13.11
Optimal Solution for Arid Company

SOLUTION

The total cost is \$167,000.

Ship 12,000 units from Battle Creek to Rochester @ \$4.25.	Cost =	\$51,000
Ship 6,000 units from Cherry Creek to Worchester @ \$4.00.	Cost =	\$24,000
Ship 4,000 units from Cherry Creek to Rochester @ \$5.00.	Cost =	\$20,000
Ship 6,000 units from Dee Creek to Rochester @ \$4.50.	Cost =	\$27,000
Ship 12,000 units from Dee Creek to Dorchester @ \$3.75.	Cost =	\$45,000
	Total =	\$167,000

Solved Problem 4

An electronics manufacturer must expand by building a second facility. The search is narrowed to four locations, all of which are acceptable to management in terms of dominant factors. Assessment of these sites in terms of seven location factors is shown in Table 13.3. For example, location A has a factor score of 5 (excellent) for labor climate; the weight for this factor (20) is the highest of any.

Calculate the weighted score for each location. Which location should be recommended?

SOLUTION

Based on the weighted scores shown in Table 13.4, location C is the preferred site, although location B is a close second.

TABLE 13.3 FACTOR INFORMATION FOR ELECTRONICS MANUFACTURER

Location Factor	Factor Weight	Factor Score for Each Location			
		A	B	C	D
1. Labor climate	20	5	4	4	5
2. Quality of life	16	2	3	4	1
3. Transportation system	16	3	4	3	2
4. Proximity to markets	14	5	3	4	4
5. Proximity to materials	12	2	3	3	4
6. Taxes	12	2	5	5	4
7. Utilities	10	5	4	3	3

TABLE 13.4 CALCULATING WEIGHTED SCORES FOR ELECTRONICS MANUFACTURER

		Weighted Score for Each Location			
Location Factor	Factor Weight	A	B	C	D
1. Labor climate	20	100	80	80	100
2. Quality of life	16	32	48	64	16
3. Transportation system	16	48	64	48	32
4. Proximity to markets	14	70	42	56	56
5. Proximity to materials	12	24	36	36	48
6. Taxes	12	24	60	60	48
7. Utilities	10	50	40	30	30
Totals	100	348	370	374	330

Discussion Questions

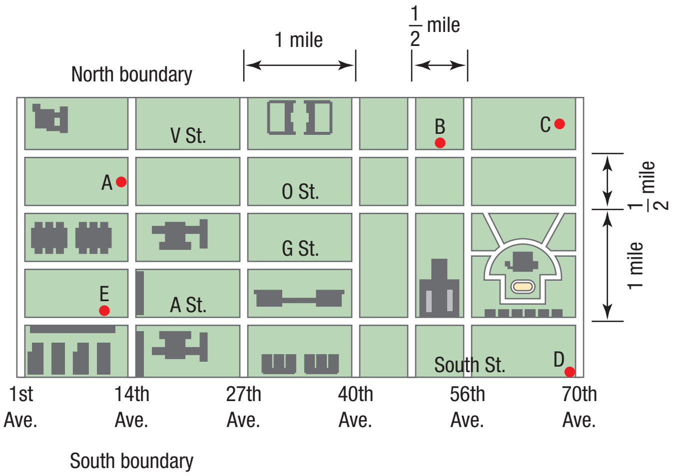
1. Select two organizations, one in services and one in manufacturing. What are the key factors that each organization would consider in locating a new facility? What data would you want to collect before evaluating the location options, and how would you collect the data? Explain.
2. The chapter opener shows BMW's rationale behind opening a plant in South Carolina. The entire process took several years, required careful planning, and incurred several million dollars in research fees. Assuming that in a competitive global environment business, decisions need to be implemented quickly, use examples from the case to discuss the factors that needed to be considered. Explain why the process had to be carefully planned.
3. Hospitality businesses, such as fast-food restaurants, need to be located close to their customers as opposed to manufacturing plants that can be located farther away. Consequently the demographics of the intended location need to be taken into account. The regional manager of a growing fast-food chain has asked you to select a set of implementation sites in a new country. Discuss how you would use geographical information systems in making location decisions.

Problems

The OM Explorer and POM for Windows software is available to all students using the 11th edition of this textbook. Go to **http://www.pearsonglobaleditions.com/krajewski** to download these computer packages. If you purchased MyOMLab, you also have access to Active Models software and significant help in doing the following problems. Check with your instructor on how best to use these resources. In many cases, the instructor wants you to understand how to do the calculations by hand. At the least, the software provides a check on your calculations. When calculations are particularly complex and the goal is interpreting the results in making decisions, the software entirely replaces the manual calculations.

Load–Distance Method

1. The following three points are the locations of important facilities in a transportation network: (20, 20), (50, 10), and (50, 60). The coordinates are in miles.
   a. Calculate the Euclidean distances (in miles) between each of the three pairs of facilities.
   b. Calculate these distances using rectilinear distances.
2. West Gorham High School is to be located at the population center of gravity of three communities: Westbrook, population 17,500; Scarborough, population 18,000; and Gorham, population 30,000. Westbrook is located at 43.6769°N, 70.3717°W; Scarborough is located at 43.5781°N, 70.3222°W; and Gorham is located at 43.6795°N, 70.4447°W.
   a. Where should West Gorham High School be located?
   b. If only two pieces of adequate land are available for sale: Baker's Field at 43.6618°N, 70.3622°W, or Lonesome Acres at 43.5753°N, 70.3367°W, using rectilinear distances, which is closer to the site located in part (a)?
3. Val's Pizza is looking for a single central location to make pizza for delivery only. This college town is arranged on a grid with arterial streets, as shown in Figure 13.12. The main campus (A), located at 14th and R, is the source of 4,000 pizza orders per week. Three smaller campuses (B, C, and D) are located at 52nd and V, at 67th and Z, and at 70th and South. Orders from the smaller campuses average 1,000 pizzas per week. In addition, the State Patrol headquarters (E) at 10th and A orders 500 pizzas per week.



▲ **FIGURE 13.12**
Map of Campus Area

   a. At about what intersection should Val start looking for a suitable site? (Estimate coordinates for the major demands accurate to the nearest one-quarter mile, and then find the center of gravity.)
   b. What is the rectilinear weekly load–distance score for this location?
   c. If the delivery person can travel 1 mile in 2 minutes on arterial streets and ¼ mile per minute on residential streets, going from the center of gravity location to the farthest demand location will take how long?
4. A larger and more modern main post office is to be constructed at a new location in Davis, California. Growing suburbs caused a shift in the population density from where it was 40 years ago, when the current facility was built. Annette Werk, the postmaster, asked her assistants to draw a grid map of the seven points where mail is picked up and delivered in bulk. The coordinates and trips per day to and from the seven mail source points and the current main post office, M, are shown in the following table. M will continue to act as a mail source point after relocation.

Mail Source Point	Round Trips Per Day	*x, y* Coordinates (miles)
1	1	(13, 2)
2	2	(14, 9)
3	4	(16, 11)
4	2	(6, 5)
5	8	(7, 15)
6	4	(4, 7)
7	1	(9, 8)
M	5	(18, 8)

   a. Calculate the center of gravity as a possible location for the new facility (round to the nearest whole number).
   b. Compare the load–distance scores for the location in part (a) and the current location, using rectilinear distance.
5. Rauschenberg Manufacturing is investigating which locations would best position its new plant relative to three important customers (located in cities A, B, and C). As shown in the table below, all three customers require multiple daily deliveries. Management limited the search for this plant to those three locations and compiled the following information:

Location	Coordinates (miles)	Deliveries per day
A	(100, 200)	8
B	(400, 100)	4
C	(100, 100)	3

   a. Which of these three locations yields the smallest total travel distance, based on Euclidean distances?
   b. Which of these locations is best, based on rectilinear distances?
   c. What are the coordinates of the center of gravity?
6. A personal computer manufacturer plans to locate its assembly plant in Taiwan and to ship its computers back to the United States through either Los Angeles or San Francisco. It has distribution centers in Atlanta, New York, and Chicago and will ship to them from whichever city is chosen as the port of entry on the west coast. Overall transportation cost is the only criterion for choosing the port. Use the load–distance model and the information in Table 13.5 to select the more cost-effective city.

TABLE 13.5 DISTANCES AND COSTS FOR PC MANUFACTURER

		Distribution Center (units/year)		
		Chicago	Atlanta	New York
		10,000	**7,500**	**12,500**
	Los Angeles			
	Distance (miles)	1,800	2,600	3,200
	Shipping cost ($/unit)	0.0017/mile	0.0017/mile	0.0017/mile
PORT OF ENTRY				
	San Francisco			
	Distance (miles)	1,700	2,800	3,000
	Shipping cost ($/unit)	0.0020/mile	0.0020/mile	0.0020/mile

7. D Oscar's Bowling, Inc., wants to break into the Phoenix metropolitan market with one of its super-sized 200 lane, 24-hour bowling alleys. It, however, only has enough capital to build one facility. Oscar wants it to be centered by population, as determined by the center of gravity method. The following information is given:

City	Population	*x* coordinate	*y* coordinate
Tempe	250,000	5	5
Scottsdale	400,000	5	10
Chandler	300,000	5	0
Mesa	700,000	10	1
Glendale	350,000	1	10

a. Where should Oscar build?

b. If Oscar wanted to relocate to the closest city near his new facility, where would he live?

Break-Even Analysis

8. Two alternative locations are under consideration for a new plant: Jackson, Mississippi, and Dayton, Ohio. The Jackson location is superior in terms of costs. However, management believes that sales volume would decline if this location were chosen because it is farther from the market, and the firm's customers prefer local suppliers. The selling price of the product is $325 per unit in either case. Use the following information to determine which location yields the higher total profit per year:

Location	Annual Fixed Cost	Variable Cost per Unit	Forecast Demand per Year
Jackson	$2,050,000	$75	27,500 units
Dayton	$2,500,000	$95	35,000 units

9. Fall-Line, Inc., is a Great Falls, Montana, manufacturer of a variety of downhill skis. Fall-Line is considering four locations for a new plant: Aspen, Colorado; Medicine Lodge, Kansas; Broken Bow, Nebraska; and Wounded Knee, South Dakota. Annual fixed costs and variable costs per pair of skis are shown in the following table:

Location	Annual Fixed Costs	Variable Cost per Pair
Aspen	$8,000,000	$250
Medicine Lodge	$2,400,000	$130
Broken Bow	$3,400,000	$90
Wounded Knee	$4,500,000	$65

a. Plot the total cost curves for all the communities on a single graph (see Solved Problem 2). Identify on the graph the range in volume over which each location would be best.

b. What break-even quantity defines each range?

Although Aspen's fixed and variable costs are dominated by those of the other communities, Fall-Line believes that both the demand and the price would be higher for skis made in Aspen than for skis made in the other locations. The following table shows those projections:

Location	Price per Pair	Forecast Demand per Year
Aspen	$500	60,000 pairs
Medicine Lodge	$350	45,000 pairs
Broken Bow	$350	43,000 pairs
Wounded Knee	$350	40,000 pairs

D = **Difficult Problem**

c. Determine which location yields the highest total profit per year.

d. Is this location decision sensitive to forecast accuracy? At what minimum sales volume does Aspen become the location of choice?

10. Wiebe Trucking, Inc., is planning a new warehouse to serve the western United States. Denver, Santa Fe, and Salt Lake City are under consideration. For each location, annual fixed costs (rent, equipment, and insurance) and average variable costs per shipment (labor, transportation, and utilities) are listed in the following table. Sales projections range from 500,000 to 600,000 shipments per year.

Location	Annual Fixed Costs	Variable Costs per Shipment
Denver	$4,800,000	$4.55
Santa Fe	$4,500,000	$6.20
Salt Lake City	$3,200,000	$7.50

a. Plot the total cost curves for all the locations on a single graph.

b. Which city provides the lowest overall costs?

11. Sam Hutchins is planning to operate a specialty bagel sandwich kiosk but is undecided about whether to locate in the downtown shopping plaza or in a suburban shopping mall. Based on the following data, which location would you recommend?

Location	Downtown	Suburban
Annual rent, including utilities	$11,500	$7,000
Expected annual demand (sandwiches)	32,500	25,500
Average variable costs per sandwich	$1.40	$0.95
Average selling price per sandwich	$3.75	$2.50

12. D Dennison Manufacturing makes large helical springs used in aircraft landing gear. The company has narrowed its potential choices for its new manufacturing facility to four cities. The following information is known about the manufacturing and shipping costs of locating in each of these four cities:

	Fixed Costs per Year	Variable Manufacturing Costs per Unit	Variable Shipping Costs per Unit
Phoenix	$300,000	$70.00	$5.00
Buffalo	$600,000	$56.00	$4.00
Seattle	$1,500,000	$36.00	$2.00
Atlanta	$1,750,000	$42.00	$5.00

a. Use break-even point analysis to determine where Dennison should locate.

b. Based solely on break-even quantity, if Dennison's manufacturing forecast for the foreseeable future is 40,000 units annually, where should he locate?

Transportation Method

13. Prescott Industries transports sand and stone extracted from its open-pit mines located in Odessa and Bryan to its concrete block manufacturing facilities in Abilene, Tyler, and San Angelo. For the capacities, locations, and shipment costs per truckload shown in the Figure 13.13, determine the shipping pattern that will minimize transportation costs. What are the estimated transportation costs associated with this optimal allocation pattern?

Source	Destination: Abilene	Destination: Tyler	Destination: San Angelo	Capacity
Odessa	$60	$50	$40	12,000
Bryan	$70	$30	$90	10,000
Demand	8,000	10,000	4,000	22,000

▲ **FIGURE 13.13**
Transportation Tableau for Prescott Industries

14. The Winston Company has four distribution centers (A, B, C, and D) that require 40,000, 60,000, 30,000, and 50,000 gallons of de-ionized water, respectively, per month for cleaning their long-haul trucks. Three de-ionized water wholesalers (1, 2, and 3) indicated their willingness to supply as many as 50,000, 70,000, and 60,000 gallons, respectively. The total cost (shipping plus price) of delivering 1,000 gallons of de-ionized water from each wholesaler to each distribution center is shown in the following table:

	Distribution Center			
Wholesaler	**A**	**B**	**C**	**D**
1	$1.30	$1.40	$1.80	$1.60
2	$1.30	$1.50	$1.80	$1.60
3	$1.60	$1.40	$1.70	$1.50

a. Determine the optimal solution. Show that all capacities have been exhausted and that all demands can be met with this solution.

b. What is the total cost of the solution?

15. *The Acme Company operates four factories that ship products to five warehouses. The shipping costs, requirements capacities, and optimal allocations are shown in Figure 13.14. What is the total cost of the optimal solution?

D = Difficult Problem

Factory	Shipping Cost per Case to Warehouse					Capacity
	W1	W2	W3	W4	W5	
F1	$1 60,000	$3 20,000	$4	$5	$6	80,000
F2	$2	$2	$1 50,000	$4 10,000	$5	60,000
F3	$1	$5	$1	$3 20,000	$1 40,000	60,000
F4	$5	$2 50,000	$4	$5	$4	50,000
Demand	60,000	70,000	50,000	30,000	40,000	250,000

▲ **FIGURE 13.14**
Optimal Solution for Acme Company

16. D The Giant Farmer Company processes food for sale in discount food stores. It has two plants: one in Chicago and one in Houston. The company also operates warehouses in Miami, Florida; Denver, Colorado; Lincoln, Nebraska; and Jackson, Mississippi. Forecasts indicate that demand soon will exceed supply and that a new plant with a capacity of 8,000 cases per week is needed. The question is where to locate the new plant. Two potential sites are Buffalo, New York, and Atlanta, Georgia. The two tables at the bottom of this page give data on capacities, forecasted demand, and shipping costs that have been gathered.

For each alternative new plant location, determine the shipping pattern that will minimize total transportation costs. Where should the new plant be located?

Plant	Capacity (Cases per Week)	Warehouse	Demand (Cases per Week)
Chicago	10,000	Miami	7,000
Houston	7,500	Denver	9,000
New plant	8,000	Lincoln	4,500
	Total 25,500	Jackson	5,000
			Total 25,500

Plant	Shipping Cost to Warehouse (per Case)			
	Miami	**Denver**	**Lincoln**	**Jackson**
Chicago	$7.00	$2.00	$4.00	$5.00
Houston	$3.00	$1.00	$5.00	$2.00
Buffalo (alternative 1)	$6.00	$9.00	$7.00	$4.00
Atlanta (alternative 2)	$2.00	$10.00	$8.00	$3.00

17. D Consider the facility location problem at the Giant Farmer Company described in Problem 16. Management is considering a third site, at Memphis. The shipping costs per case from Memphis are $3 to Miami, $11 to Denver, $6 to Lincoln, and $5 to Jackson. Find the minimum cost plan for an alternative plant in Memphis. Would this result change the decision in Problem 16?

18. D The Thor International Company operates four factories that ship products to five warehouses. The shipping costs, requirements, and capacities are shown in Figure 13.15. Use the transportation method to find the shipping schedule that minimizes shipping cost.

19. D Consider further the Thor International Company situation described in Problem 18. Thor decides to close F4

Factory	Shipping Cost per Case to each Warehouse						Capacity
	W1	W2	W3	W4	W5	Dummy	
F1	$2	$3	$3	$2	$6	$0	50,000
F2	$2	$3	$2	$4	$5	$0	80,000
F3	$4	$2	$4	$2	$3	$0	80,000
F4	$3	$4	$4	$5	$2	$0	40,000
Demand	45,000	30,000	30,000	35,000	50,000	60,000	250,000

▲ **FIGURE 13.15**
Transportation Tableau for Thor International

because of high operating costs. The logistics manager is worried about the effect of this move on transportation costs. Currently, F4 is shipping 40,000 units to W5 at cost of $80,000 [or 40,000($2)]. If this warehouse were to be served by F1 (currently not being used), the cost would increase to $240,000 [or 40,000(6)]. As a result, the Ajax logistics manager requests a budget increase of $160,000 (or $240,000 − $80,000).

a. Should the logistics manager get the budget increase?

b. If not, how much would you budget for the increase in shipping costs?

20. D The Chambers Corporation produces and markets an automotive theft-deterrent product, which it stocks in various warehouses throughout the country. Recently, its market research group compiled a forecast indicating that a significant increase in demand will occur in the near future, after which demand will level off for the foreseeable future. The company decides to satisfy this demand by constructing new plant capacity. Chambers already has plants in Baltimore and Milwaukee and has no desire to relocate those facilities. Each plant is capable of producing 600,000 units per year.

After a thorough search, the company developed three site and capacity alternatives. Alternative 1 is to build a 600,000-unit plant in Portland. Alternative 2 is to build a 600,000-unit plant in San Antonio. Alternative 3 is to build a 300,000-unit plant in Portland and a 300,000-unit plant in San Antonio. The company's four warehouses distribute the

D = Difficult Problem

product to retailers. The market research study provided the following data.

Warehouse	Expected Annual Demand
Atlanta (AT)	500,000
Columbus (CO)	300,000
Los Angeles (LA)	600,000
Seattle (SE)	400,000

The logistics department compiled the following cost table specifying the cost per unit to ship the product from each plant to each warehouse in the most economical manner, subject to the reliability of the various carriers involved.

Plant	Warehouse			
	AT	CO	LA	SE
Baltimore	$0.35	$0.20	$0.85	$0.75
Milwaukee	$0.55	$0.15	$0.70	$0.65
Portland	$0.85	$0.60	$0.30	$0.10
San Antonio	$0.55	$0.40	$0.40	$0.55

As one part of the location decision, management wants an estimate of the total distribution cost for each alternative. Use the transportation method to calculate these estimates.

A Systematic Location Selection Process

21. Calculate the weighted score for each location (A, B, C, and D) shown in Table 13.6. Which location would you recommend?

22. John and Jane Darling are newlyweds trying to decide among several available rentals. Alternatives were scored on a scale of 1 to 5 (5 = best) against weighted performance criteria, as shown in Table 13.7. The criteria included rent, proximity to work and recreational opportunities, security, and other neighborhood characteristics associated with the couple's values and lifestyle. Alternative A is an apartment, B is a bungalow, C is a condo, and D is a downstairs apartment in Jane's parents' home.

Which location is indicated by the preference matrix? What qualitative factors might cause this preference to change?

TABLE 13.6 | FACTORS FOR LOCATIONS A–D

		Factor Score for Each Location			
Location Factor	Factor Weight	A	B	C	D
1. Labor climate	5	5	4	3	5
2. Quality of life	30	2	3	5	1
3. Transportation system	5	3	4	3	5
4. Proximity to markets	25	5	3	4	4
5. Proximity to materials	5	3	2	3	5
6. Taxes	15	2	5	5	4
7. Utilities	15	5	4	2	1
Total	100				

TABLE 13.7 | FACTORS FOR NEWLYWEDS

		Factor Score for Each Location			
Location Factor	Factor Weight	A	B	C	D
1. Rent	25	3	1	2	5
2. Quality of life	20	2	5	5	4
3. Schools	5	3	5	3	1
4. Proximity to work	10	5	3	4	3
5. Proximity to recreation	15	4	4	5	2
6. Neighborhood security	15	2	4	4	4
7. Utilities	10	4	2	3	5
Total	100				

23. Wagner Remodelers Inc. is looking for a new city in which to relocate their home remodeling business. The company employs highly skilled craftspeople who rehabilitate old housing. Most of their current craftspeople will relocate with the company; however, additional works at the new location will be hired. The most important location factors for the company were weighted and three target cities were scored against these factors.

Location Factor	Factor Weight	Factor Score for Each City		
		Coptic	Sparta	Royce
1. Proximity to run-down housing stock	15	3	5	1
2. Community population size	15	3	5	5
3. Proximity to the sources of building materials	5	5	5	5
4. Transportation infrastructure	5	5	1	5
5. Availability of skilled workers	10	5	2	5
6. Favorable zoning processes	15	5	5	5
7. Low city property tax rates	5	5	3	3
8. Availability of excellent primary education	5	3	1	5
9. Availability of family entertainment	5	3	1	5
10. Attitude of community to building rehabilitation	10	2	3	3
11. Proximity to real estate sales firms	10	2	5	5
Total	100			

a. Which location is indicated by the preference matrix?

b. Would the best location change if the company decided not to relocate any of its current craftspeople but instead hire only from the population at their new location? Assume that factors 8 and 9 are now given no weight and factor 5 is twice as important.

24. Silky Industries is looking for a location for its second telephone remanufacturing facility. Two cities are under consideration. The two most important location factors are: Factor A "availability of resources" and Factor B "availability of customers." However, the company is having great difficulty assigning relative weights to these factors.

Location Factor	Factor Weight	Factor Score for Each City	
		Blake	Irmo
A. Availability of resources		5	6
B. Availability of customers		10	7
Total	100		

Assuming that the factor weights must sum to 100, what range of weights would make Blake the superior location?

Active Model Exercise

Active Model 13.1 appears in MyOMLab. It allows you to find the location that minimizes the total load–distance score.

QUESTIONS

1. What is the total load–distance score to the new HealthWatch medical facility if it is located at the center of gravity?
2. Fix the *y* coordinate, and use the scroll bar to modify the *x* coordinate. Can you reduce the total load–distance score?
3. Fix the *x* coordinate, and use the scroll bar to modify the *y* coordinate. Can you reduce the total load–distance score?
4. The center of gravity does not necessarily find the site with the minimum total load–distance score. Use both scroll bars to move the trial location, and see whether you can improve (lower) the total load–distance score.

VIDEO CASE Continental Tire: Pursuing a Winning Plant Decision

As the world's largest automotive company and fourth-largest tire manufacturer, Continental's global business operations cover a diverse set of enterprises. Perhaps best known for its passenger and light truck tires, this sector of the Hanover, Germany-based company's total tire activities only comprise about 30% of total revenues, which topped 33 billion euro ($44.5 billion USD) in 2013. The rest comes from chassis and safety equipment, powertrain, interior systems such as infotainment and navigation, and its ContiTech division that produces marine hoses, conveyer belts, vehicle springs, and other automotive hoses and trim components. With over 300 manufacturing sites in 49 countries, the company recently undertook an ambitious $500 million project to build a new passenger and light truck (PLT) tire plant near its customers in the United States and Canada.

While the decision at hand focused on locating a single facility, it is a decision that was impacted by Continental's existing U.S.-based manufacturing plants in Mount Vernon, Illinois, and other plants in Mexico, Europe and Latin America. Plants in the network operate independently of one another, yet may share raw materials sources and customers such as Walmart or Ford Motor Company. The existing network of warehouses and distribution centers located within the United States to handle the distribution needs had to be considered. Of particular concern was the cost of labor in the production of tires, which led senior management to direct Scott Barnette, Central Controller of the Americas–Finance, to analyze two potential locations with perceived low labor costs: Mexico and Costa Rica.

Scott was well-aware that three of Continental's four core values—trust, passion to win, and freedom to act—empowered him to explore beyond the locations initially favored by the company. The fourth core value, "for one another," that encompasses teamwork also played a role. So, when he suggested adding a potential location in the United States to the list that might meet or exceed established internal rate of return hurdles, he was instructed to go ahead, but to continue with a primary focus on Mexico and Costa Rica.

In 2011, Scott began gathering all the necessary data to incorporate into his linear programming optimization software program. This program was designed to analyze all costs, called "landed costs" at Continental, which covered the entire stream from raw materials through to the customer, not just production costs at the plant. Approaches used in the past focused more on production costs rather than landed costs. Raw materials include natural rubber from Asia, synthetic rubber from Germany and Japan, textiles from Georgia and Asia, steel from Asia and domestic sources, chemicals from numerous global sources, and carbon black – the powdered petroleum processing by-product that makes tires black and helps enhance durability. Continental is not a vertically integrated enterprise so all materials must be procured from these global sources.

The seven groups of factors that dominate manufacturing plant location decisions, as noted in this text, were all present for Continental. Prior to construction of the new plant, Continental had been importing tires for the U.S. and Canadian markets from Europe and Asia. The initial production output from the new plant would be 4 million tires annually to meet this demand. Company estimates for growth in domestic demand placed the need for an additional 4 million units per year from this plant, so Scott made sure the company's location choice had adequate room for expansion. Additional acreage at the plant site with ample energy access was critical. The remaining global demand of 22 million units would be handled by plants in Illinois, Brazil, Europe, India and China, near to those markets.


Pearson

Using state-of-the-art technology, Continental Tire makes four million tires annually at its new Sumpter, South Carolina manufacturing facility. The $500 million investment created nearly 1,600 new jobs and greatly enhanced the economy of South Carolina.

In a typical location decision, most organizations create five-year models to fully understand the impact of their choices. After all, locating a physical plant is a huge investment intended to span decades of operations. For Scott and Continental, a 20-year model was created. With a plan to invest up to $500 million dollars and create close to 1,600 jobs, Scott wanted to be sure the effect of any mid-term, location-specific community incentives such as real estate, tax, and other breaks wouldn't cloud the long-term cash and profitability picture.

After considering both the Mexican and Costa Rican sites, twelve U.S. locations were scoped, and eventually narrowed down to South Carolina. The state had a history of stable business, manufacturing experience, low manufacturing costs, an international influence, a proactive business approach, and a solid logistics infrastructure with both the Port of Charleston and major highways nearby. The chosen site near Sumter, South Carolina also had a small but experienced manufacturing population of approximately 60,000 people who could immediately benefit from the new plant's investment.

After considering Scott's analysis, Continental awarded Sumter the plant and broke ground in March of 2012. It took an average of 300 people over 626,000 hours to complete the construction. Operations started in late October 2013, and full ramp up and expansion are expected to run through 2021. It's now the largest land site for manufacturing of any kind in the world for the company. When company officials were asked what the intended use was for the sizeable plot of land they purchased, they simply smiled and responded, "We have big plans, and we are not constructing a golf course."

QUESTIONS

1. Consider the dominant factors for manufacturing as described in the text. Briefly describe how each one may have influenced Continental's decision to locate its new plant in Sumter, South Carolina instead of Mexico or Costa Rica.
2. South Carolina is also home to manufacturing plants for major tire competitors Michelin and Bridgestone. How might these two plants factor into the company's location decision?
3. Explain why locating a plant solely on the basis of low labor costs may be the wrong approach.

CASE R.U. Reddie for Location

The R.U. Reddie Corporation, located in Chicago, manufactures clothing specially designed for stuffed cartoon animals such as Snoopy and Wile E. Coyote. Among the popular products are a wedding tuxedo for Snoopy and a flak jacket for Wile E. Coyote. The latter is capable of stopping an Acme rocket at close range—sometimes.

For many sales, the company relies upon the help of spoiled children who refuse to leave the toy store until their parents purchase a wardrobe for their stuffed toys. Rhonda Ulysses Reddie, owner of the company, is concerned over the market projections that indicate demand for the product is substantially greater than current plant capacity. The "most likely" projections indicate that the company will be short by 400,000 units next year, and thereafter 700,000 units annually. As such, Rhonda is considering opening a new plant to produce additional units.

Background

The R.U. Reddie Corporation currently has three plants located in Boston, Cleveland, and Chicago. The company's first plant was the Chicago location, but as sales grew in the Midwest and Northeast, the Cleveland and Boston plants were built in short order. As the demand for wardrobes for stuffed animals moved west, warehouse centers were opened in St. Louis and Denver. The capacities of the three plants were increased to accommodate the demand. Each plant has its own warehouse to satisfy demands in its own area. Extra capacity was used to ship the product to St. Louis or Denver.

The new long-term forecasts provided by the sales department contain both good news and bad news. The added revenues will certainly help Rhonda's profitability, but the company would have to buy another plant to realize the added profits. Space is not available at the existing plants, and the benefits of the new technology for manufacturing stuffed animal wardrobes are tantalizing. These factors motivate the search for the best location for a new plant. Rhonda identifies Denver and St. Louis as possible locations for the new plant.

Rhonda's Concerns

A plant addition is a big decision. Rhonda has started to think about the net present value of each alternative as it will be an important factor in making the final decision. She also wanted to take into account the non-quantifiable factors. First, the availability of a good workforce is much better in Denver than St. Louis because of the recent shutdown of a Beanie Baby factory. The labor market is much tighter in St. Louis and the prognosis is for continued short supply in the foreseeable future. Second, the Denver metropolitan area just instituted strict environmental regulations. Rhonda's new plant would adhere to existing laws, but the area is highly environmentally conscious, and more regulations may be coming in the future. It is costly to modify a plant once operations begin. Finally, Denver has a number of good suppliers with the capability to assist in production design (new wardrobe fashions). St. Louis also has suppliers, but they cannot help with product development. Proximity to suppliers with product development capability is a "plus" for this industry.

Data

The following data have been gathered for Rhonda:

1. The per-unit shipping cost based on the average ton-mile rates for the most efficient carriers is $0.0005 per mile. The average revenue per outfit is $8.00.
2. The company currently has the following capacity (in thousands) constraints:

	Capacity
Boston	400
Cleveland	400
Chicago	500

3. Data concerning the various locations are found in Table 13.8.
4. New plant information:

Alternative	Building and Equipment[2]	Annual Fixed Costs (SGA)[1,3]	Variable roduction Costs/Unit	Land[1]
Denver	$12,100	$550	$3.15	$1,200
St. Louis	10,800	750	3.05	800

[1] Figures are given in thousands.

[2] Net book value of plant and equipment with remaining depreciable life of 10 years.

[3]Annual fixed costs do not include depreciation on plant and equipment.

TABLE 13.8 LOCATION DATA FOR R.U. REDDIE

City	Most Likely Demand First Year[1]	Most Likely Demand After Years 2-10[1]	Current Costs, Building and Equipment[1,2]	Annual Fixed Costs (SGA)[1,3]	Variable Production Costs/Unit	Land[1]
Boston	80	140	$9,500	$600	$3.80	$500
Cleveland	200	260	7,700	300	3.00	400
Chicago	370	430	8,600	400	3.25	600
St. Louis	440	500				
Denver	610	670				

[1]Figures are given in thousands.

[2]Net book value of plant and equipment with remaining depreciable life of 10 years.

[3]Annual fixed costs do not include depreciation on plant and equipment.

5. The road mileage between the cities is as follows:

	Boston	Cleveland	Chicago	St. Louis	Denver
Boston	—	650	1,000	1,200	2,000
Cleveland		—	350	600	1,400
Chicago			—	300	1,000
St. Louis				—	850
Denver					—

6. Basic assumptions you should follow:

- Terminal value (in 10 years) of the new investment is 50 percent of plant, equipment, and land cost.
- The tax rate is 40 percent.
- Straight-line depreciation is used for all assets over a 10-year life.
- R.U. Reddie is a 100 percent equity company with all equity financing and a weighted average cost of capital (WACC) of 11 percent.
- Capacity of the new plant production for the first year will be 500 (000) units.
- Capacity of the new plant production thereafter will be 900 (000) units.
- Cost of goods sold (COGS) equals variable costs of production plus total transportation costs.
- Costs to ship from a plant to its own warehouse are zero; however, variable production costs are applicable.

7. R.U. Reddie operations and logistics managers determined the shipping plan and cost of goods sold for the option of *not* building a new plant and simply using the existing capacities to their fullest extent (status quo solution).

Year 1	COGS = 4,692,000
Boston to Boston	80
Boston to St. Louis	320
Cleveland to Chicago	80
Cleveland to Cleveland	200
Cleveland to St. Louis	120
Chicago to Chicago	290
Chicago to Denver	210

Years 2–10	COGS = $4,554,000
Boston to Boston	140
Boston to St. Louis	260
Cleveland to Cleveland	260
Cleveland to St. Louis	140
Chicago to Chicago	430
Chicago to St. Louis	70

QUESTIONS

Your team has been asked to determine whether R.U. Reddie should build a new plant and, if so, where it should be located.

1. Write a memo from your team to R.U. Reddie indicating your recommendation and a brief overview of the supporting evidence.
2. Use the transportation method for location problems and POM for Windows to find the optimal distribution pattern and the cost of goods sold for both the Denver and St. Louis alternatives. First solve the problem with Denver as the new plant and then do the same for St. Louis. The unit costs for each cell of the transportation matrix should be the sum of the shipping costs and the variable costs of production. For example, the unit costs for producing and shipping a unit from Denver to Boston would be ($3.15 = 0.0005(2000)) = $4.15. Use Figures 13.4 and 13.5 as guides in your formulation. The "optimal cost" in each case will be the cost of goods sold.
3. Compute the NPV of each alternative. Use the results from the transportation models for the COGS for each alternative. (*Hint:* Your analysis will be simplified if you think in terms of incremental cash flows.) Create an easy-to-read spreadsheet for each alternative.

Addendum

Here are some hints for your analysis.

1. Define your variables to be "thousands of units shipped," and omit the three zeroes after each demand and capacity value. Then remember to multiply your final decisions and total variable costs by a thousand after you get your solution from the model.
2. Because the capacity and demand changes from year 1 to year 2, you need to run your model twice for each location to get the necessary data.

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Ian Dagnall/Alamy

The cruise liner *Coral Princess* awaits food and supplies at the Cruise Terminal in the Port of Los Angeles, San Pedro, Los Angeles, California.

14

INTEGRATING THE SUPPLY CHAIN

Coral Princess

Regardless of where you are right now, or what the weather is like in your home town, think of lounging on the deck of the *Coral Princess* somewhere in the Caribbean just after passing through the Panama Canal. The view is gorgeous, the breezes soft and cool; you find it difficult to contemplate that you and 1974 other guests are in a top-rated hotel with amenities that range from an outdoor movie theater to a casino with every game of chance a gambler ever wanted. If you want a wedding, there is a chapel. There is a swimming pool with a retractable glass dome, a cigar bar, and a complete TV studio.

While all those amenities sound good, there is one thing that all cruise liner guests look forward to and that is eating. There are five high-quality restaurants on board the *Coral Princess*. When the meals arrive in front of you, have you ever wondered how they got there? The supply of food, and its preparation, puts a tremendous strain on the coordination of supply chain processes for the *Coral Princess*. Here, four days at sea, the hotel manager just cannot call the suppliers and say that he forgot the carrots, the butter, and the sugar. Running out of stock is not an acceptable option. Pure volume is a complicating factor. On an average 15-day cruise, the *Coral Princess* will use 175 tons of food, including 43,200 eggs, 2,425 pounds of pasta, 7,245 pounds of rice, 84,000 pounds of vegetables, 13,000 pounds of chicken, 8,800 pounds of fish, and 10,500 pounds of beef. Two hundred galley employees prepare over 10,000 meals daily, all washed down with 3,800 bottles of wine and 12,000 bottles or cans of beer a cruise. Not everything is purchased, nor can all 175 tons of food be stored on board at one time. Certain items such as ice cream, dessert pastries, and breads are produced onboard to ensure their freshness. Other items must be restocked at selected ports on a schedule put in place long in advance of the cruise. While the guests are enjoying a port of call, the ship personnel are restocking the hold with food from suppliers in that area that have been proven to supply the best quality. Cruise ships must be very careful not to accept food that will cause sickness onboard.

Even a well-oiled wagon can run off the road, and so it can with the supply chain of a cruise ship. Good planning, including contingency plans, and quick reactions are desirable attributes. Natural disasters, such as hurricanes or earthquakes, cause cruise ships to reschedule their ports of call, which can disrupt the scheduled supply of food, boutique items, hotel supplies, and maintenance items. All of this requires close coordination up and down the supply chain. For example, the massive Japanese earthquake and tsunami of March 11, 2011, not only caused cruise ships to revise their itineraries, but it will also affect the supply chain for a very long time, given the scare from radiation getting into the food supply. Another example of a disruptive event is a strike at a port of supply for a cruise ship. A labor strike at the Ports of Los Angeles and Long Beach caused a massive congestion of 70 vessels waiting to be unloaded, thereby putting pressure on Princess Cruises' schedule for replenishing a cruise ship headed for Mexico. The solution was to use trucks to move part of the shipment in ocean freight containers to go by sea using a vessel at the Port of Oakland, 450 miles away, and the rest of the shipment by land using 53-foot trailers, timed so that both shipments would meet the cruise ship in Mexico. The two loads required considerable coordination for health inspections, security, customs clearance, and refrigerated equipment.

Cruise ships strive to provide the best possible experience for their guests. High levels of supply chain integration across multiple commodity groups and suppliers, as well as numerous ordering, delivery, and stocking points, are at the heart of that effort.

Source: Handout, *The Coral Princess Food & Beverage Department* (August 16, 2011); News archive at **http://www.princess.com/news/article**; Case Study Cruise Line Logistics-Princess Cruises, *Agility Logistics*, **http://www.agilitylogistics.com**.

Using Operations to Create Value

PROCESS MANAGEMENT

Process Strategy and Analysis
Managing Quality
Planning Capacity
Managing Process Constraints
Designing Lean Systems
Managing Effective Projects

CUSTOMER DEMAND MANAGEMENT

Forecasting Demand
Managing Inventories
Planning and Scheduling Operations
Efficient Resource Planning

SUPPLY CHAIN MANAGEMENT

Designing Effective Supply Chains
Supply Chains and Logistics
→ **Integrating the Supply Chain**
Managing Supply Chain Sustainability

LEARNING GOALS *After reading this chapter, you should be able to:*

1. Identify the major causes of disruptions in a supply chain.
2. Describe the four major nested processes in the new service or product development process.
3. Explain the five major nested processes in the supplier relationship process and use total cost analysis and preference matrices to identify appropriate sources of supply.
4. Identify the four major key nested processes in the order fulfillment process and use the expected value decision rule to determine the appropriate capacity of logistic resources.
5. Define the three major nested processes in the customer relationship process.
6. Explain how firms can mitigate the operational, financial, and security risks in a supply chain.

The development and delivery of services and products has become increasingly complex in today's global economy. The *Coral Princess*, one of several cruise liners owned and operated by the Princess Cruise Line, is an example of how a firm can excel at coordinating its supply chain for competitive advantage. To be effective, accurate inventory and demand information has to be available combined with considerable collaboration between the ship and its suppliers along the cruise itinerary. The Princess Cruise Line is successful at **supply chain integration**, which is the effective coordination of supply chain processes through the seamless flow of information up and down the supply chain. Supply chain integration provides each member of the supply chain visibility into the capacities and inventories of other members of the supply chain to aid in planning and scheduling. It facilitates collaboration between firms in a supply chain; in effect, it is an enabler of supply chain management and is at the core of reducing the risks of supply disruption.

supply chain integration

The effective coordination of supply chain processes through the seamless flow of information up and down the supply chain.

Supply chain integration involves internal as well as external processes. Figure 14.1 shows just how interconnected processes and firms in a supply chain can be. Think of a supply chain as a river that flows from raw material suppliers to consumers. For example, a ketchup factory gets its major supply from the tomato paste factories, which for the ketchup factory is a tier 1 supplier. In turn, the tomato paste factories get their major supplies from the tomato grading stations, which are tier 2 suppliers of the ketchup factory. Finally, the tomato growers ship their product directly to the tomato grading stations. The tier 1, tier 2, and tier 3 suppliers are all *upstream* from the ketchup factory, which means that they control the flow of supply to the ketchup factory. Suppose the tomato paste factory has a major process failure. The flow of tomato paste to the ketchup factory would dwindle to a trickle, as if someone built a dam across a river. Indeed, even those entities *downstream* from the ketchup factory could feel the effects after inventories of ketchup have been consumed. When a link in the supply chain fails, whether it is an internal process or one at a supplier, the rest of the chain feels the effects.

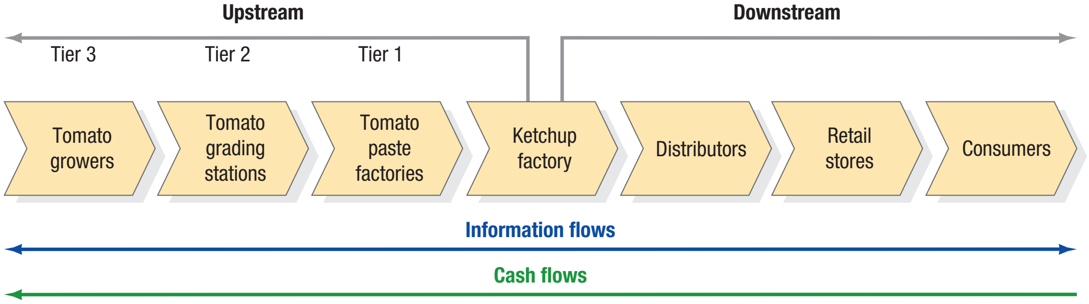


FIGURE 14.1 Supply Chain for a Ketchup Factory

Mitigating the effects of supply chain disruptions is an important benefit of supply chain integration. Information flows, both upstream and downstream, provide visibility to supply chain members regarding supplies, capacities, and plans. Cash flows move upstream and are affected by pricing, promotional programs, supply contracts, and exchange rates. Every supply chain faces an undeniable risk in operational disruptions, security failures, and financial performance. Understanding the implications of these disruptions for supply chain performance is important for all employees in an organization.

In this chapter, we begin by discussing the nature and impact of disruptions to supply chain operations. We then explore the four major processes involved in supply chain integration and how they are linked internally and externally. We finish the chapter with a discussion of **supply chain risk management**, which is the practice of managing the risk of any factor or event that can materially disrupt a supply chain, whether within a single firm or across multiple firms.

supply chain risk management

The practice of managing the risk of any factor or event that can materially disrupt a supply chain, whether within a single firm or across multiple firms.

Supply Chain Disruptions

When a company expands from a local or regional presence to a more global one, supply chain strategy often needs to be adjusted. In a global arena, different products are directed to more diverse customers via different distribution channels, which require different supply chains. These supply chains are typically more complex and are exposed to both domestic and international disruptions. In this section, we identify the causes of supply chain disruptions, discuss how they cause supply chain dynamics, and show how supply chain integration can mitigate those effects.

Causes of Supply Chain Disruptions

Supply chain disruptions could result in cost increases, loss of reputation, civil and criminal penalties, bankruptcy, lost customers, or reduced revenue, profit, and market share. The more complex the supply chain, the less predictable the likelihood and the impact of a disruption, and the greater the risk to the effectiveness of the supply chain. Disruptions can emanate from outside the firm as well as inside the firm.

Philip Scalia/Alamy

The Kinzua Viaduct Bridge in northwest Pennsylvania, constructed in 1882, was the longest railroad bridge in the world, spanning 2,053 feet and reaching a maximum height of 301 feet. It facilitated the flow of raw materials from the east to the great lakes regions. The trestle bridge was destroyed by a tornado in 2003. It takes reminders such as this to highlight the importance of integrated supply chains to avoid disrupting the flow of products and supplies.

External Causes A firm has the least amount of control over its external customers and suppliers, who can periodically cause disruptions. Typical external disruptions include the following:

- *Environmental Disruptions.* Natural disasters, terrorism, political instability or war affecting supplier operations, regulatory changes, quotas, and strikes all can disrupt the normal flow of materials and services in a supply chain.
- *Supply Chain Complexity.* Increases in the dependencies between supply chain entities (suppliers, partners, and customers), increases in the number of supply chain entities, and changes in the configuration of the extended supply chain (the suppliers to suppliers) all have the potential to cause disruptions in the supply of materials, products, and services.
- *Loss of Major Accounts.* A loss of significant demand volume is the result of losing a large customer. This disruption is compounded when the firm has a concentrated customer base.
- *Loss of Supply.* Losing the supply of key materials or services can slow down or even stop the operations in a supply chain. Downtime due to equipment failures or quality issues is a common cause. This disruption is amplified if the firm is too consolidated in its supply markets.
- *Customer-Induced Volume Changes.* Customers may change the quantity of a customized service or product they had ordered for a specific date or they may unexpectedly demand more of a standard service or product. If the market demands short lead times, the firm needs a quick reaction from its suppliers.
- *Service and Product Mix Changes.* Customers may change the mix of items in an order and cause a ripple effect throughout the supply chain. For example, a major appliance store chain may change the mix of washing machines in its orders from 60 percent Whirlpool brand and 40 percent Kitchen Aid brand to 40 percent Whirlpool and 60 percent Kitchen Aid. This decision changes the production schedule of the Whirlpool plant that makes both brands, causing imbalances in its inventories. In addition, the tier 1 supplier that makes the face plates for the washing machines must change its schedules, thereby affecting *its* suppliers.
- *Late Deliveries.* Late deliveries of materials or delays in essential services can force a firm to switch its schedule from production of one product model to another. Firms that supply model-specific items may have their schedules disrupted. For example, the Whirlpool plant may find that a component supplier for its Model A washing machine could not supply the part on time. To avoid shutting down the assembly line, which is an expensive action, Whirlpool may decide to switch to Model B production. Suddenly, the demand on the suppliers of Model B-specific parts increases.
- *Underfilled Shipments.* Suppliers that send partial shipments do so because of disruptions at their own plants. The effects of underfilled shipments are similar to those of late shipments unless the underfilled shipment contains enough materials to allow the firm to operate until the next shipment.

Internal Causes A firm's own operations can be the culprit in what becomes the source of constant disruption in the supply chain. Typical internal disruptions include the following:

- *Internally Generated Shortages.* A shortage of parts manufactured by a firm may occur because of machine breakdowns, lengthy setup times, limited capacity and bottlenecks, or inexperienced workers. Internal shortages can cause a change in the firm's production schedule, thus affecting suppliers.
- *Quality Failures.* Product recalls, such as the record number of automobiles recalled by General Motors in 2013 and 2014, can cause huge costs and supply chain disruptions. Even if quality failures do not involve product recalls, they restrict the flow of services or products and negatively affect the performance of the supply chain.
- *Poor Supply Chain Visibility.* The inability to "see" the inventories and capabilities of suppliers and the inventories of customers, as well as the pipeline of materials and products, poses a risk to the performance of a firm. Often this risk arises because of a lack of collaborative planning and forecasting (see Chapter 8, "Forecasting Demand").

- *Engineering Changes.* Changes to the design of services or products can have a direct impact on suppliers. For example, a major fast-food restaurant switching from Styrofoam packaging to biodegradable packaging for its sandwiches will affect the demand experienced by the suppliers of Styrofoam.
- *Order Batching.* Suppliers may offer a quantity discount, which gives an incentive to firms to purchase large quantities of an item less frequently, thereby raising the variability in orders to the supplier. Order batching may also result in transportation economies; larger orders may enable full-truckload shipments, thereby reducing the cost to ship materials but creating more variability in the supply chain.
- *New Service or Product Introductions.* A firm decides on the number of new service or product introductions, as well as their timing, and hence introduces a dynamic in the supply chain. New services or products may even require a new supply chain or the addition of new members to an existing supply chain. The more complex a service or product is, the greater is the risk of a disruption.
- *Service or Product Promotions.* A common practice of firms producing standardized services or products is to use price discounts to promote sales. Price discounting creates a spike in demand that is felt throughout the supply chain.
- *Information Errors.* Demand forecast errors can cause a firm to order too many or too few services and materials or can precipitate expedited orders that force suppliers to react more quickly to avoid shortages in the supply chain. In addition, errors in the physical count of items in stock can cause shortages (leading to panic purchases) or too much inventory (leading to a slowdown in purchases). Finally, communication links between buyers and suppliers can be faulty.

Supply Chain Dynamics

Why do these disruptions pose a risk to supply chain operations? Each firm in a supply chain depends on other firms for services, materials, or the information needed to supply its immediate external customer in the chain. Because firms are typically owned and managed independently, the actions of downstream supply chain members (positioned nearer the end user of the service or product) can affect the operations of upstream members. The reason is that upstream members of a supply chain must react to the demands placed on them by downstream members of the chain. These demands are a function of the policies downstream firms have for replenishing their inventories, the actual levels of those inventories, the demands of their customers, and the accuracy of the information they have to work with. As you examine the order patterns of firms in a supply chain, you will frequently see the variability in order quantities increase as you proceed upstream. This increase in variability is referred to as the **bullwhip effect**, which gets its name from the action of a bullwhip—the handle of the whip initiates the action; however, the tip of the whip experiences the wildest action. The slightest change in customer demands can ripple through the entire chain, with each member receiving more variability in demands from the member immediately downstream. A firm contributes to the bullwhip effect if the variability of the orders to its suppliers exceeds the variability of the orders from its immediate customers.

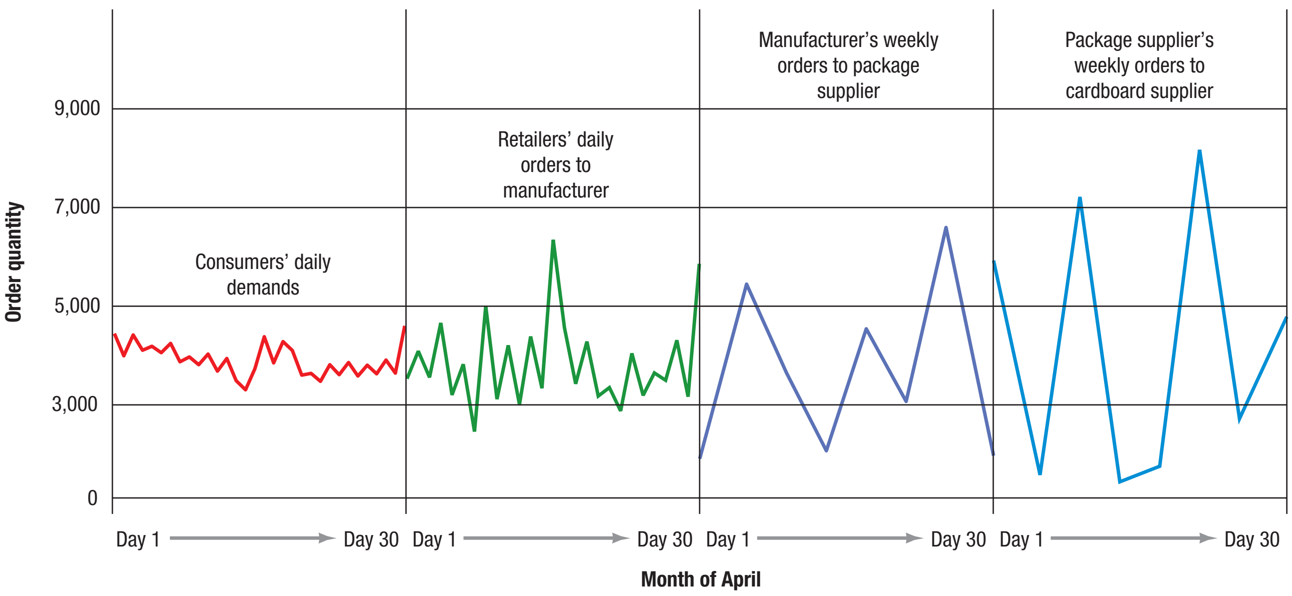
bullwhip effect

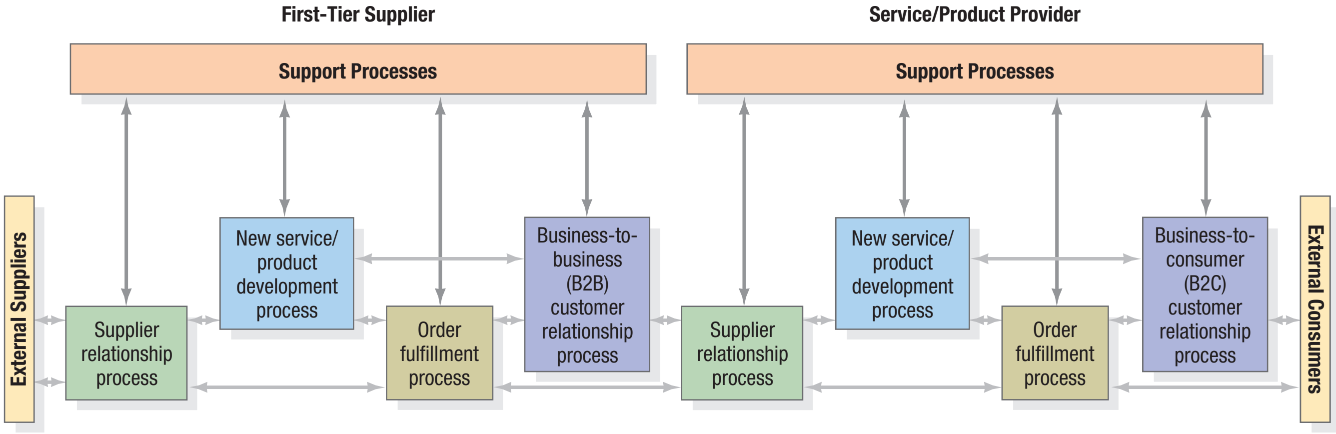
The phenomenon in supply chains whereby ordering patterns experience increasing variance as you proceed upstream in the chain.

Figure 14.2 shows the bullwhip effect in a supply chain for facial tissue. The variability in the orders increases as you go upstream in the supply chain. Because supply patterns do not match demand

MyOMLab Animation

FIGURE 14.2
Supply Chain Dynamics for Facial Tissue





▲ **FIGURE 14.3**
External Supply Chain Linkages

patterns, inventories accumulate in some firms and shortages occur in others. The firms with too much inventory stop ordering, and those that have shortages place expedited orders.

Integrated Supply Chains

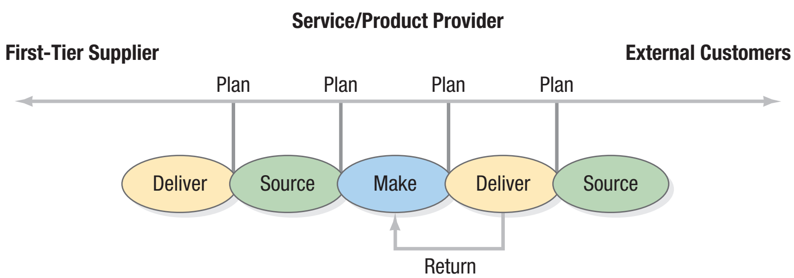
Regardless of the supply chain design, minimizing supply chain disruptions begins with a high degree of functional and organizational integration. Such integration does not happen overnight; it must include linkages between the firm and its suppliers and customers, as shown in Figure 14.3. The new service or product development, supplier relationship, order fulfillment, and customer relationship processes, as well as their internal and external linkages, are integrated into the normal business routine. The firm takes on a customer orientation. However, rather than merely reacting to customer demand, the firm strives to work with its customers and suppliers so that everyone benefits from improved flows of services, materials, and information. The firm must also develop a better understanding of its suppliers' organizations, capacities, strengths, and weaknesses—and include its suppliers earlier into the design of new services or products.

SCOR model

A framework that focuses on a basic supply chain of plan, source, make, deliver, and return processes, repeated again and again along the supply chain.

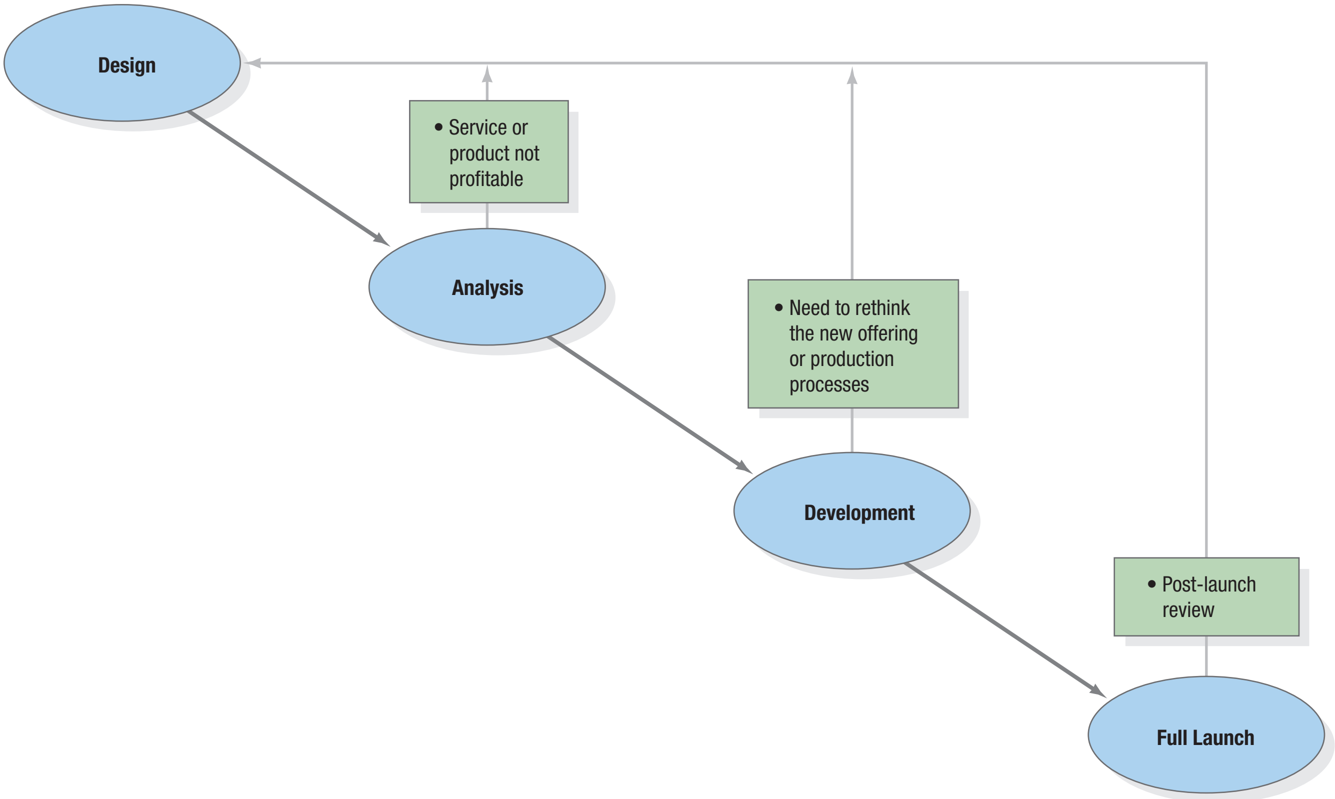
Another integrative frame of reference is the *supply chain operations reference model*, known as *SCOR*, developed by the Supply Chain Council with the assistance of 70 of the world's leading manufacturing companies. Figure 14.4 shows that the **SCOR model** focuses on a basic supply chain of *plan*, *source*, *make*, *deliver*, and *return* processes, repeated again and again along the supply chain. The return processes handle the return of recyclable materials and defective products, which we will discuss in more detail in Chapter 15, "Managing Supply Chain Sustainability." Much like our model shown in Figure 14.3, the SCOR model emphasizes that the design of an integrated supply chain is complex and requires a *process view*. We already provided some key insights into process design decisions in Part 1 and Part 2 of the text. These insights must be applied to the new service or product development, supplier relationship, order fulfillment, and customer relationship processes. Beyond that, these processes need to be integrated both within a firm and across the supply chain. It is important to know that an integrated supply chain, implied by Figure 14.3 and the SCOR model in Figure 14.4, provides a framework for the operating decisions in a firm and that these processes play a major role.

FIGURE 14.4 ▶
SCOR Model



New Service or Product Development Process

Competitive priorities help managers develop services and products that customers want. New services or products are essential to the long-term survival of the firm. *New* refers to both brand new services or products or major changes to existing services or products. The new service or product development process is an integral element in a firm's supply chain because it defines the nature of the materials, services, and information flows the supply chain must support. As shown in Figure 14.5, it begins with the



▲ **FIGURE 14.5**
New Service/Product Development Process

consideration of the development strategy and ends with the launch of the new offering. There are four key nested processes, or stages, in the new service or product development process: design, analysis, development, and full launch. Here are some considerations for supply chain managers.

Design

The *design* stage is critical because it links the creation of new services or products to the corporate strategy of the firm and defines the requirements for the firm's supply chain. As we have already noted, the corporate strategy specifies the long-term objectives and the markets in which the firm wishes to compete. In the design stage, ideas for new offerings are proposed and screened for feasibility and market worthiness. These ideas specify how the customer connects with the service or manufacturing firm, the benefits and outcomes for the customer, and the value of the service or product. Proposals also specify how the new offering will be produced and delivered—an important consideration for the supply chain. Often critical choices must be made, such as the raw materials, degree of modularity in the design, or the nature of the logistical services needed to get the service or product to market. Even though many of the detailed specifics of the service or product and its processes have not yet been developed, the inputs of designers, engineers, suppliers, supply chain managers, and potential customers in this stage can avoid costly mistakes.

Analysis

The second stage, *analysis*, involves a critical review of the new offering and how it will be produced to make sure that it fits the corporate strategy, is compatible with regulatory standards, presents an acceptable market risk, and satisfies the needs of the intended customers. The resource requirements for the new offering must be examined from the perspective of the core capabilities of the firm and the need to acquire additional resources. The existing supply chain must be evaluated for its appropriateness for the new offering. If change is needed, the design might have to be revised (efficient or responsive) or new capabilities acquired by forming strategic partnerships with new firms. If the analysis reveals that the new offering has good market potential and that the firm has the capability (or can acquire it), the authorization is given to proceed to the next stage.

Development

The third stage, *development*, brings more specificity to the new offering. The required competitive priorities are used as inputs to the design (or redesign) of the processes that will be involved in delivering the new offering. The processes are analyzed, including those of suppliers; each activity is designed to meet its required competitive priorities and to add value to the service or product. Once the new offering is specified and the capability of the processes verified, the market program can be designed. Finally, personnel are trained and some pilot runs can be conducted to iron out the kinks in production and supply. At this stage it is possible that some unforeseen problems may arise, forcing a reconsideration of the service or product or the processes required to produce it. The supply chain might have to be redesigned as well.

concurrent engineering

A concept that brings product engineers, process engineers, marketers, buyers, information specialists, quality specialists, and suppliers together to design a product and the processes that will meet customer expectations.

To avoid costly mismatches between the design of a new offering and the capability of the processes and supply chain required to produce it, many firms engage in a concept called **concurrent engineering**, which brings product engineers, process engineers, marketers, buyers, information specialists, quality specialists, and suppliers together to design a product and the processes that will meet customer expectations. Changes are much simpler and less costly at this stage. However, problems with the design of the new offering or the capability to deliver it may be discovered during this stage. The proposal for the new offering may have to be scrapped or completely rethought.

Full Launch

The final stage, *full launch*, involves the coordination of many internal processes as well as those both upstream and downstream in the supply chain. Promotions for the new offering must be initiated, sales personnel briefed, distribution processes activated, and old services or products that the new offering is to replace withdrawn. A particular strain is placed on the supply chain during a period referred to as *ramp-up*, when the production processes must increase volume to meet demands while coping with quality problems and last-minute design changes. The more integrated the supply chain, the easier the ramp-up period. Flexibility in the supply chain is a desirable attribute during the ramp-up period. Later, as the service or product matures and volume increases sufficiently, a supply chain based on efficiency may have to be developed.

Regardless of the service or product, a post launch review should compare the competitive priorities of the supply chain to its competitive capabilities, perhaps signaling a need to rethink the original service or product idea or the supply chain. The review should also get inputs from customers, who may divulge their experiences and may share ideas for change.

Supplier Relationship Process

The nature of the service or product determines the design requirements for the upstream supply chain. The supplier relationship process, which focuses on the interaction of the firm with upstream suppliers, includes five major nested processes: (1) sourcing, (2) design collaboration, (3) negotiation, (4) buying, and (5) information exchange. For many firms, these processes are the organizational responsibility of **purchasing**, which is the activity that decides the suppliers to use, negotiates contracts, maintains information flows, and determines whether to buy locally.

purchasing

The activity that decides which suppliers to use, negotiates contracts, and determines whether to buy locally.

Sourcing

The sourcing process is involved in the selection, certification, and evaluation of suppliers and, in general, the management of supply contracts.

Supplier Selection A starting point for selecting suppliers is to perform a total cost analysis. There are four key costs to consider for each supplier.

- *Material costs.* Negotiating with suppliers for the provision of a service or product results in a price per unit (or application of the service). Material costs equal annual requirements (D) multiplied by the price per unit, p.

$$\text{Annual material costs} = pD$$

- *Freight costs.* The costs of transporting the product or the equipment and personnel who will perform the service can vary greatly depending on the location of the supplier, the size of the shipments (full truckload shipments [TL] are cheaper per pound than less-than-truckload shipments [LTL]), the number of shipments per year, and the mode of transportation (air transportation is more expensive than truck or rail transportation).
- *Inventory costs.* Buyers interested in purchasing products must consider the shipping quantity and the lead time from the supplier. The shipping quantity, Q, will determine the cycle inventory the buyer must maintain until the next shipment of the product.

$$\text{Cycle inventory} = Q/2$$

The lead time, L, and the average requirements per day (or week) $\bar{d}$, will determine the level of the pipeline inventory, which also may be the responsibility of the buyer. Assuming a constant lead time,

$$\text{Pipeline inventory} = \bar{d}L$$

The buyer must pay inventory holding costs on the cycle and pipeline inventories. Annual inventory costs equal the sum of the cycle and pipeline inventories multiplied by the annual holding cost per unit, H. See Chapter 9, "Managing Inventories" for a review of inventory holding costs and cycle and pipeline inventories.

$$\text{Annual inventory costs} = (Q/2 + \bar{d}L)H$$

- *Administrative costs.* Supply contacts must be monitored and frequent interactions with the supplier may be required. Administrative costs include the managerial time, travel, and other variable costs associated with interacting with a supplier. These costs may vary greatly depending on the location of the supplier; more distant suppliers typically require more administrative attention.

The total annual cost for a supplier is the sum of these costs:

$$\text{Total Annual Cost} = pD + \text{Freight costs} + (Q/2 + \bar{d}L)H + \text{Administrative costs}$$

EXAMPLE 14.1 Total Cost Analysis for Supplier Selection

Compton Electronics manufactures laptops for major computer manufacturers. A key element of the laptop is the keyboard. Compton has identified three potential suppliers for the keyboard, each located in a different part of the world. Important cost considerations are the price per keyboard, freight costs, inventory costs, and contract administrative costs. The annual requirements for the keyboard are 300,000 units. Assume Compton has 250 business days a year. Managers have acquired the following data for each supplier.

	ANNUAL FREIGHT COSTS		
	Shipping Quantity (Units/Shipment)		
Supplier	**10,000**	**20,000**	**30,000**
Belfast	\$380,000	\$260,000	\$237,000
Hong Kong	\$615,000	\$547,000	\$470,000
Shreveport	\$285,000	\$240,000	\$200,000

	KEYBOARD COSTS AND SHIPPING LEAD TIMES			
Supplier	**Price/Unit**	**Annual Inventory Carrying Cost/Unit**	**Shipping Lead Time (Days)**	**Administrative Costs**
Belfast	\$100	\$20.00	15	\$180,000
Hong Kong	\$96	\$19.20	25	\$300,000
Shreveport	\$99	\$19.80	5	\$150,000

Which supplier provides the lowest annual total cost to Compton?

SOLUTION

The average requirements per day are

$$\bar{d} = 300{,}000/250 = 1{,}200 \text{ keyboards.}$$

Each option must be evaluated with consideration for the shipping quantity using the following equation:

$$\begin{aligned}\text{Total Annual Cost} &= \text{Material costs} + \text{Freight costs} + \text{Inventory costs} + \text{Administrative costs}\\ &= pD + \text{Freight costs} + (Q/2 + \bar{d}L)H + \text{Administrative costs}\end{aligned}$$

For example, consider the Belfast option for a shipping quantity of $Q = 10{,}000$ units. The costs are

$$\begin{aligned}\text{Material costs} &= pD = (\$100/\text{unit})(300{,}000 \text{ units}) = \$30{,}000{,}000\\ \text{Freight costs} &= \$380{,}000\\ \text{Inventory costs} &= (\text{cycle inventory} + \text{pipeline inventory})H = (Q/2 + \bar{d}L)H\\ &= (10{,}000 \text{ units}/2 + 1{,}200 \text{ units/day }(15 \text{ days}))\$20/\text{unit/year} = \$460{,}000\\ \text{Administrative costs} &= \$180{,}000\\ \textbf{Total Annual Cost} &= \$30{,}000{,}000 + \$380{,}000 + \$460{,}000 + \$180{,}000 = \$31{,}020{,}000\end{aligned}$$

The total costs for all three shipping quantity options are similarly calculated and are contained in the following table.

	TOTAL ANNUAL COSTS FOR THE KEYBOARD SUPPLIERS		
	Shipping Quantity		
Supplier	**10,000**	**20,000**	**30,000**
Belfast	$31,020,000	$31,000,000	$31,077,000
Hong Kong	$30,387,000	$30,415,000	$30,434,000
Shreveport	$30,352,800	$30,406,800	$30,465,800

DECISION POINT

Notice that the shipping quantity plays an important role; the lowest cost for the Belfast supplier comes with a shipping quantity of 20,000 keyboards. Nonetheless, based on the total cost analysis, the Shreveport supplier will provide the lowest cost to Compton. Compton should choose a shipping quantity of 10,000 keyboards, which implies that there will be 30 shipments a year (or 300,000/10,000). While the Hong Kong supplier had the lowest price per keyboard, the Shreveport supplier could deliver the keyboards to Compton with the lowest overall cost, which includes logistics, inventory, and administrative costs.

While total cost is an important consideration in the selection of suppliers, other performance dimensions may also be important. The quality of a supplier's materials may be critical since hidden costs of poor quality may be high. Similarly, shorter lead times and on-time delivery may allow the buying firm to maintain acceptable customer service with less inventory. So management must review the market segments it wants to serve and accordingly relate its supplier selection needs to the supply chain. Competitive priorities and order winners for the firm are a good starting point in developing a list of performance criteria to be used. For example, if you were a manager of a food-service firm, in addition to total costs, you would likely use on-time delivery and quality as top criteria for selecting suppliers. These criteria reflect the requirements that food-service supply chains need to meet.

Another criterion that is important in the selection of suppliers is environmental impact. Many firms are engaging in **green purchasing**, which involves identifying, assessing, and managing the flow of environmental waste and finding ways to reduce it and minimize its impact on the environment. Suppliers are being asked to be environmentally conscious when designing and producing their services or products. Claims such as *green*, *biodegradable*, *natural*, and *recycled* must be substantiated when bidding on a contract. In the not-too-distant future, this criterion could become an important one in the selection of suppliers. We will have more to say about this topic in Chapter 15, "Managing Supply Chain Sustainability."

green purchasing

The process of identifying, assessing, and managing the flow of environmental waste and finding ways to reduce it and minimize its impact on the environment.

When faced with multiple criteria in the supplier selection problem, management can use a preference matrix as shown in Example 14.2. See Supplement A, "Decision Making Models" for a review of this approach.

EXAMPLE 14.2 Using a Preference Matrix for Selecting Suppliers

The management of Compton Electronics has done a total cost analysis for three international suppliers of keyboards (see Example 14.1). Compton also considers on-time delivery, consistent quality, and environmental stewardship in its selection process. Each criterion is given a weight (total of 100 points), and each supplier is given a score (1 = poor, 10 = excellent) on each criterion. The data are shown in the following table.

		SCORE		
Criterion	**Weight**	**Belfast**	**Hong Kong**	**Shreveport**
Total Cost	25	5	8	9
On-Time Delivery	30	9	6	7
Consistent Quality	30	8	9	6
Environment	15	9	6	8

SOLUTION

The weighted score for each supplier is calculated by multiplying the weight by the score for each criterion and arriving at a total. For example, the Belfast weighted score is

$$WS = (25 \times 5) + (30 \times 9) + (30 \times 8) + (15 \times 9) = 770$$

Similarly, the weighted score for Hong Kong is 740, and for Shreveport, 735. Consequently, Belfast is the preferred supplier.

DECISION POINT

Even though Belfast had a higher total cost based on the calculations in Example 14.1, it significantly outperformed the other suppliers on the criteria Compton considered very important. Given the weights placed on the criteria, it is clear that Compton is willing to pay extra for better delivery performance, quality, and environmental stewardship.

Supplier Certification and Evaluation Supplier certification programs verify that potential suppliers have the capability to provide the services or materials the buying firm requires. ISO 9001:2008 is one such program (see Chapter 3, "Managing Quality," for more details). Nonetheless, certification typically involves site visits by a cross-functional team from the buying firm, which does an in-depth evaluation of the supplier's capability to meet cost, quality, delivery, and flexibility targets from process and information system perspectives. The team may consist of members from operations, purchasing, engineering, information systems, and accounting. Every aspect of producing the services or materials is explored. The team observes the supplier's processes in action and reviews the documentation for completeness and accuracy. Once certified, the supplier can be used by the purchasing department without its having to make background checks.

Certification does not give the supplier a free pass on future evaluation. Performance is regularly monitored and performance records are kept. Periodic visits by the certification team may take place. Recertification may be required after a certain period of time or if performance declines.

Design Collaboration

The design collaboration process focuses on jointly designing new services or products with key suppliers; it facilitates concurrent engineering by drawing key suppliers into the new service/product development process, particularly in the design and development stages. This process seeks to eliminate costly delays and mistakes incurred when many suppliers concurrently design service packages or manufactured components.

An approach that many firms are using in their design collaboration process is called **early supplier involvement**, which is a program that includes suppliers in the design phase of a service or product. Suppliers provide suggestions for design changes and materials choices that will result in more efficient operations and higher quality. In the automotive industry, an even higher level of early supplier involvement is known as **presourcing**, whereby suppliers are selected early in a product's concept

PRNewsFoto/BIOTA Brands of America, Inc./AP Photos

BIOTA's premium natural spring water originates from one of the world's highest protected alpine springs perched above Ouray, Colorado, and is packaged in the world's first biodegradable bottle. Made from corn, a 100 percent renewable resource, BIOTA bottles break down in approximately 80 days in a commercial composting environment.

early supplier involvement

A program that includes suppliers in the design phase of a service or product.

presourcing

A level of supplier involvement in which suppliers are selected early in a product's concept development stage and are given significant, if not total, responsibility for the design of certain components or systems of the product.

value analysis

A systematic effort to reduce the cost or improve the performance of services or products, either purchased or produced.

competitive orientation

A supplier relation that views negotiations between buyer and seller as a zero-sum game: Whatever one side loses, the other side gains, and short-term advantages are prized over long-term commitments.

development stage and are given significant, if not total, responsibility for the design of certain components or systems of the product. Presourced suppliers also take responsibility for the cost, quality, and on-time delivery of the items they produce.

Firms can also improve performance by engaging in **value analysis**, which is a systematic effort to reduce the cost or improve the performance of services or products, either purchased or produced. It is an intensive examination of the services, materials, processes, information systems, and flows of material involved in the production of a service or an item. Benefits include reduced production, materials, and distribution costs; improved profit margins; and increased customer satisfaction.

Negotiation

The negotiation process focuses on obtaining an effective contract that meets the price, quality, and delivery requirements of the supplier relationship process's internal customers. The nature of the relations maintained with suppliers can affect the quality, timeliness, and price of a firm's services and products. The firm's orientation toward supplier relations will affect the negotiation and design collaboration processes.

Competitive Orientation The **competitive orientation** sees negotiations between buyer and seller as a zero-sum game: Whatever one side loses, the other side gains. Short-term advantages are prized over long-term commitments. The buyer may try to beat the supplier's price down to the lowest survival level or push demand to high levels during boom times and order almost nothing during recessions. In contrast, the supplier presses for higher prices for specific levels of quality, customer service, and volume flexibility. Which party wins depends largely on who has the most clout.

Purchasing power determines the clout that a firm has. A buyer has purchasing power when the purchasing volume represents a significant share of the supplier's sales or the purchased service or item is standardized and many substitutes are available. We refer to this condition as *economic dependency*. However, firms may have other sources of power in a relationship with suppliers. These sources include:

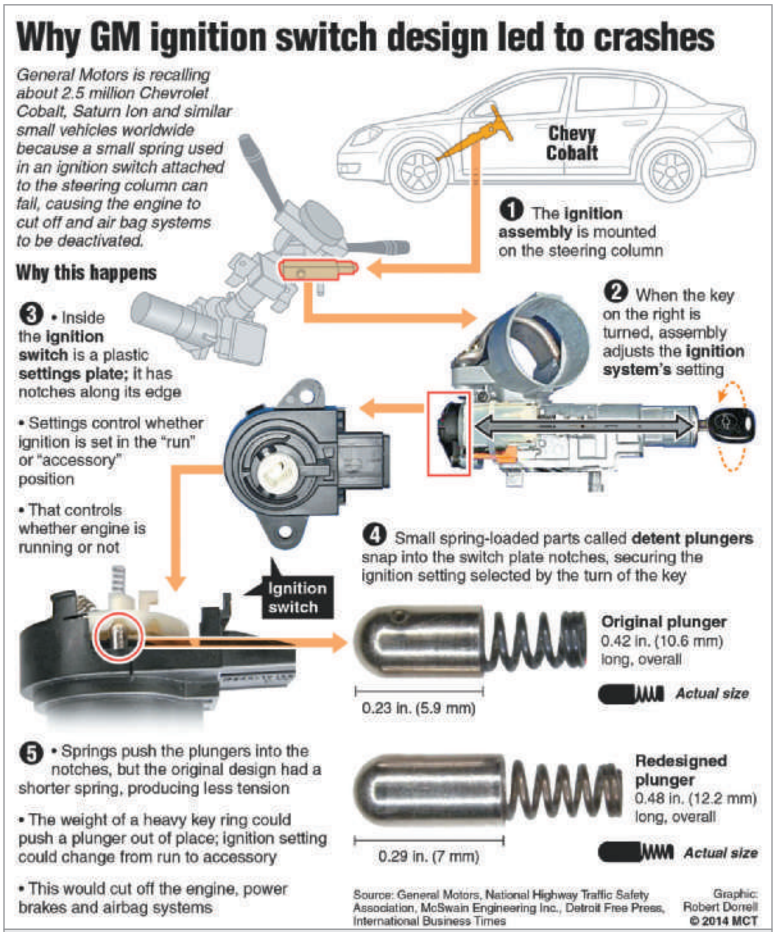
- *Referent*—the supplier values identification with the buyer. For example, the fact that a firm is supplying IBM may open the door for business with other customers.
- *Expert*—the buyer has access to knowledge, information, and skills desired by the supplier. For example, a supplier to UPS may get access to logistics planning skills possessed by UPS.
- *Reward*—the buyer has the ability to give rewards to the supplier. Often, the rewards may involve the promise for future business or the opportunity to become a partner sometime in the future.
- *Legal*—the buyer has the legal right to prescribe behavior for the supplier. For example, the buyer may demand strict compliance to the negotiated contract or else the matter will be taken to court.
- *Coercive*—the buyer has the ability to punish the supplier. For example, the buyer may threaten to cancel future business with the supplier unless the supplier adheres to the buyer's demands.

It should be noted that the buyer does not always possess the power in a relationship. Sometimes the supplier holds the power; consequently, the supplier could exercise these sources of power as well. Managerial Practice 14.1 shows how the exercise of power can go overboard.

MANAGERIAL PRACTICE 14.1 The Consequences of Power in an Automotive Supply Chain

General Motors (GM) is a $155 billion global company that designs, manufactures, markets, and distributes ten brands of vehicles and vehicle parts and sells financial services. It has 18,500 suppliers, 212,000 employees speaking 50 languages in 396 facilities in 37 countries touching six continents crossing 23 time zones, and 21,000 retail dealers worldwide. Imagine the complexity of the nested web of supply chains GM has to manage. To be successful in such an environment, a firm needs good supplier relations because economic and physical disruptions are very likely. Unfortunately for GM, the disruptions were *very* likely. In February 2014, GM issued a massive recall of 2.6 million vehicles designed and sold in the market 10 years earlier for a defective part implicated in at least 13 deaths. What went wrong?

To gain perspective, we must go back to the year 2000, when GM's profit margins were declining because of the rising costs of worker and retiree benefit obligations and eroding market share. The Chevrolet Cobalt and the Saturn Ion, the "small-car hope" of the future and the very cars that were the subject of the recall 10 years later, were being designed. GM had planned to build those cars on a common platform with the Opel Astra in conjunction with Fiat. Building a compact car off a single global platform would have generated a profit even for an inexpensive $12,000 car; stamping out millions of similar models would have created economies of scale. However, the venture with Fiat failed. Given the gloomy financial picture, GM management decided that they had to find other ways to reduce costs. While GM never advocated building unsafe cars, the message "build them for less" reflected a culture of cutting costs and squeezing suppliers. Using the power it had over suppliers in the supply chain, GM began pressing its suppliers, including former parts division Delphi Automotive Plc, to shave pennies off the price of every part to



Dorrell/MCT/Newscom

This graphic shows the tiny spring within certain GM cars' ignition systems that failed and caused multiple fatal auto accidents. The subsequent massive recall and litigation costs are a sober reminder of the possibility that even a small, inexpensive part can be critical to the safety of consumers.

match rock-bottom prices from Asia. Using *coercive* power, GM threatened to outsource the production overseas if suppliers could not match those low prices. Delphi, for example, relied on GM for 90 percent of its business; the leverage was enormous. Further, to bid on a new parts contract, suppliers had to give GM an immediate price reduction on current business. The price cuts amounted to millions of dollars. Those suppliers who won contracts had to agree on annual price cuts of 3 percent to 5 percent of the new business.

The part that spurred the recall was an ignition switch, costing between $2 and $5. A spring inside the part was loose enough to allow the ignition to switch out of the "on" position, shutting off the engine and power steering and disabling the air bags. The defect caused much damage and injury, including death. The part was initially produced in 2001 at Delphi's Mechatronics plant in Foley, Alabama, which had an expensive union contract. It is unclear as to how the pressure on prices played a role with respect to the failure of the switch; however, buckling under the pressure to cut costs in 2005, Delphi moved the plant to Metamoros, Mexico, where workers made the equivalent of $11 per day. Nonetheless, the ignition-switch fault was already known at GM by then.

From 2002 through 2005, GM had the worst supplier relations in the industry. Things went steadily downhill, and in 2009, GM filed for Chapter 11 bankruptcy. While there are many reasons for the downfall, two things are clear. First, GM lost perspective on its competitive priorities and focused almost exclusively on low-cost operations. It used the tremendous power it had to squeeze suppliers on price to the point they had to cut corners to stay in business. Second, GM forgot about the importance of good supplier relations, relying on a competitive orientation to maintain its own profit margins in light of burgeoning overhead costs.

GM has come out of 2009 much leaner and has shown that it has learned some of the hard lessons from the past. It has made sharp gains in supplier relations; it still has a long way to go. To garner better supplier relations, GM initiated the Strategic Supplier Engagement Program, which offers perks such as better access to GM purchasing and engineering executives, joint strategic planning on opportunities for growth, and training for those suppliers who are rated highly on key measures including cost containment and various cultural aspects such as open communication and technology sharing. GM will assign ratings to its 400 largest suppliers; those receiving a prime rating will have access to the new program. Apparently the "new" GM is now exercising *expert* power and *reward* power in its relationships with suppliers. It remains to be seen if GM will be able to shed all of its past negative reputation with its supply base.

Sources: Naughton, Keith, David Welch, Jeff Green, and Mina Kimes, "GM's Flawed Cars Born as Engineers Pushed Suppliers for Low 'China Cost'," Bloomberg, **http://finance.yahoo.com** (March 21, 2014); Colias, Mike, "GM Takes Next Step to Strengthen Relationship with Suppliers," Automotive News, **http://www.autonews.com** (February 2, 2014); Wilson, Chris, "GM Leads Pack in Recalled Car Models," TIME, **http://time.com/45235** (April 1, 2014); GM Annual Report (2013), **http://www.gm.com**.

Cooperative Orientation The **cooperative orientation** emphasizes that the buyer and the seller are partners, each helping the other as much as possible. A cooperative orientation means long-term commitment, joint work on quality and service or product designs, and support by the buyer of the supplier's managerial, technological, and capacity development. A cooperative orientation favors fewer suppliers of a particular service or item, with just one or two suppliers being the ideal number. As order volumes increase, the supplier gains economies of scale, which lowers costs. When contracts are large and a long-term relationship is ensured, the supplier might even build a new facility and hire a new workforce, perhaps relocating close to the buyer's plant. Suppliers become almost an extension of the buyer.

cooperative orientation

A supplier relation in which the buyer and seller are partners, each helping the other as much as possible.

A cooperative orientation means that the buyer shares more information with the supplier about its future buying intentions. This forward visibility allows suppliers to make better, more reliable forecasts of future demand. The buyer visits suppliers' plants and cultivates cooperative attitudes. The buyer may even suggest ways to improve the suppliers' operations. This close cooperation with suppliers could even mean that the buyer does not need to inspect incoming materials. It also could mean involving the supplier more in designing services or products, implementing cost-reduction ideas, and sharing in savings.

One advantage of a cooperative orientation is that of reducing the number of suppliers in the supply chain, which reduces the complexity of managing them. However, reducing the number of suppliers for a service or item may increase the risk of an interruption in supply. It also means less opportunity to drive a good bargain unless the buyer has a lot of clout. **Sole sourcing**, which is the awarding of a contract for a service or item to only one supplier, can amplify any problems with the supplier that may crop up.

sole sourcing
The awarding of a contract for a service or item to only one supplier.

Both the competitive and cooperative orientations have their advantages and disadvantages. The key is to use the approach that serves the firm's competitive priorities best. Some companies utilize a mixed strategy, applying a competitive approach for its commodity-like supplies and a cooperative approach for its complex, high-valued, or high-volume services and materials.

Buying

The buying process relates to the actual procurement of the service or material from the supplier. This process includes the creation, management, and approval of purchase orders and determines the locus of control for purchasing decisions. Although not all purchasing opportunities involve the Internet, virtual marketplaces have provided firms with many opportunities to improve their buying and information exchange processes. Here we discuss four approaches to e-purchasing: (1) electronic data interchange, (2) catalog hubs, (3) exchanges, and (4) auctions, and close with the implications of choosing a locus of control.

electronic data interchange (EDI)
A technology that enables the transmission of routine business documents having a standard format from computer to computer over telephone or direct leased lines.

Electronic Data Interchange A traditional form of e-purchasing is **electronic data interchange (EDI)**, a technology that enables the transmission of routine, standardized business documents from computer to computer over telephone or direct leased lines. Special communications software translates documents into and out of a generic form, allowing organizations to exchange information even if they have different hardware and software components. Invoices, purchase orders, and payments information are some of the routine documents that EDI can handle—it replaces the phone call or mailed document.

catalog hubs
A system whereby suppliers post their catalog of items on the Internet and buyers select what they need and purchase them electronically.

Catalog Hubs **Catalog hubs** can be used to reduce the costs of placing orders to suppliers as well as the costs of the services or goods themselves. Suppliers post their catalog of items on the hub, and buyers select what they need and purchase them electronically. The hub connects the firm to potentially hundreds of suppliers through the Internet, saving the costs of EDI, which requires one-to-one connections to individual suppliers. Moreover, the buying firm can negotiate prices with individual suppliers for items such as office supplies, technical equipment, services, and so forth. The catalog that the buying firm's employees see consists only of the approved items and the prices the buyer has prenegotiated with its suppliers. Employees use their PCs to select the items they need, and the system generates the purchase orders, which are electronically dispatched to the suppliers.

exchange
An electronic marketplace where buying firms and selling firms come together to do business.

Exchanges An **exchange** is an electronic marketplace where buying firms and selling firms come together to do business. The exchange maintains relationships with buyers and sellers, making it easy to do business without the aspect of contract negotiations or other types of long-term conditions. Exchanges are often used for "spot" purchases to satisfy an immediate need at the lowest possible cost. Commodity items such as oil, steel, or energy fit this category. However, exchanges can also be used for most any item, such as hotel or hospital supplies.

auction
A marketplace where firms place competitive bids to buy something.

Auctions An extension of the exchange is the **auction**, where firms place competitive bids to buy something. For example, a site may be formed for a particular industry, and firms with excess capacity or materials can offer them for sale to the highest bidder. Bids can either be closed or open to the competition. Industries where auctions have value include used autos, steel, and chemicals. Examples involving consumers include eBay and Priceline.com. An approach that has received considerable attention is the so-called *reverse auction*, where suppliers bid for contracts with buyers. Each bid is posted, so suppliers can see how much lower their next bid must be to remain in the running for the contract. Each contract has an electronic prospectus that provides all the specifications, conditions, and other requirements that are nonnegotiable. The only thing left to determine is the cost to the buyer. Savings to the buyer can be dramatic, sometime as much as 20 to 30 percent over typical contract prices.

Locus of Control When an organization has several facilities (stores, hospitals, or plants, for example), management must decide whether to buy locally or centrally. This decision has implications for the control of supply chain flows.

Centralized buying has the advantage of increasing purchasing power by creating a situation where suppliers are economically dependent on the buyer. Savings can be significant, often on the order of 10 percent or more. Increased buying power can mean getting better service, ensuring long-term supply availability, or developing new supplier capability. Companies with overseas suppliers favor centralization because the specialized skills (e.g., understanding of foreign languages and cultures) needed to buy from foreign sources can be centralized in one location. Buyers also need to understand international commercial and contract law regarding the transfer of services and goods. Another trend that favors centralization is the growth of computer-based information systems and the Internet, which give specialists at headquarters access to data previously available only at the local level.

Probably the biggest disadvantage of centralized buying is loss of control at the local level. Centralized buying is undesirable for items unique to a particular facility. These items should be purchased locally whenever possible. The same holds for purchases that must be closely meshed with production schedules. Localized buying is also an advantage when the firm has major facilities in foreign countries because the managers there, often foreign nationals, have a much better understanding of the local culture than staff members at the home office. Also, centralized buying often means longer lead times.

Perhaps the best solution is a compromise strategy, whereby both local autonomy and centralized buying are possible. For example, the corporate purchasing group at IBM negotiates contracts on a centralized basis only at the request of local plants. Management at one of the plants then monitors the contract for all the participating plants.

Information Exchange

The information exchange process facilitates the exchange of pertinent operating information, such as forecasts, schedules, and inventory levels between the firm and its suppliers. New technology in the form of radio frequency identification facilitates the flow of inventory information. Beyond inventory information, the exchange of forecasts and other demand-related data facilitates integrating activities such as vendor-managed inventories.

Radio Frequency Identification An important requirement for any information exchange process in a supply chain context is accurate information regarding the quantity and location of inventories. A new application of an old technology presents some tantalizing benefits. **Radio frequency identification (RFID)** is a method for identifying items through the use of radio signals from a tag attached to an item. The tag has information about the item and sends signals to a device that can read the information and even write new information on the tag. Data from the tags can be transmitted wirelessly from one place to another through electronic product code (EPC) networks and the Internet, making it theoretically possible to uniquely identify every item a company produces and track it until the tag is destroyed. The use of RFID has not come without controversy, however. There has been considerable concern over security and privacy issues. Theoretically, anyone with the appropriate reader can gather the data these chips emit and use it for nefarious actions. Nonetheless, Walmart, Target, Intel, Gillette, and the Department of Defense, among a number of large retailers, manufacturers, government agencies, and suppliers, are implementing RFID in their supply chains. The use of RFID data can increase a supplier's service level and reduce theft. Gillette is using RFID to reduce the amount of razor-blade theft, which amounts to as much as 30 percent of sales.

radio frequency identification (RFID)
A method for identifying items through the use of radio signals from a tag attached to an item.

Individual firms can use RFID within their own operations and avoid costly coordination with other firms in the supply chain. Benefits of using RFID internal to the firm are limited, however, and so is the investment. The larger potential gains come with application to the supply chain. To be successful, all members of the supply chain must benefit from the investment in RFID, not just the firm pushing the project. This is particularly true for global operations. Global data synchronization using industry standards is critical to ensure that accurate and consistent product information is exchanged between trading partners—a very challenging task.

Vendor-Managed Inventories Reliable information regarding inventories up and down the supply chain allows firms to collaborate on effective ways to improve material flows. A tactic that requires a reliable information exchange process is **vendor-managed inventories (VMI)**, a system in which the supplier has access to the customer's inventory data and is responsible for maintaining the inventory level required by the customer. The inventory is on the customer's site, and often the supplier retains possession of the inventory until it is used by the customer. Companies such as Walmart and Dell leverage their market position to mandate VMI. Vendor-managed inventories have several key elements.

vendor-managed inventories (VMI)
A system in which the supplier has access to the customer's inventory data and is responsible for maintaining the inventory on the customer's site.

- *Collaborative Effort.* For VMI to succeed, the customers must be willing to allow the supplier access to their inventory information, which is facilitated by RFID but must be bolstered by information on forecasts, sales promotions, and other demand-related data. The implication is that the supplier assumes an important administrative role in the management of the inventory. Thus, an atmosphere of trust and accountability is required.

- *Cost Savings.* Suppliers and customers eliminate the need for excess inventory through better operational planning. VMI lowers costs by reducing administrative and inventory costs. Order placement costs are also reduced.
- *Customer Service.* The supplier is frequently on the customer's site and better understands the operations of the customer, improving response times and reducing stockouts.
- *Written Agreement.* It is important that both parties fully understand the responsibilities of each partner. Areas such as billing procedures, forecast methods, and replenishment schedules should be clearly specified. Further, the responsibility for obsolete inventory resulting from forecast revisions and changes in contract lengths should be included.

VMI can be used both by service providers as well as manufacturers. AT&T, Roadway Express, Walmart, Dell, Westinghouse, and Bose are among the companies that use it.

Order Fulfillment Process

The order fulfillment process produces and delivers the service or product to the firm's customers. There are four key nested processes: (1) customer demand planning, (2) supply planning, (3) production, and (4) logistics.

Customer Demand Planning

The customer demand planning (CDP) process facilitates the collaboration of a supplier and its customers for the purpose of forecasting customer requirements for a service or product. CDP is a business-planning process that enables sales teams (and customers) to develop demand forecasts as input to service-planning processes, production and inventory planning, and revenue planning. Forecasts must generally precede plans: It is not possible to make decisions on staffing levels, purchasing commitments, and inventory levels until forecasts are developed that give reasonably accurate views of demand over the forecasting time horizon. Chapter 8, "Forecasting Demand," contains many practical tools for forecasting customer demands.

Supply Planning

The supply planning process takes the demand forecasts produced by the customer demand planning process, the customer service levels and inventory targets provided by inventory management, and the resources provided by sales and operations planning to generate a plan to meet the demand. Regardless of whether the firm is producing services or a product, this process is critical for effective execution in the supply chain. See Chapter 9, "Managing Inventories," Chapter 10, "Planning and Scheduling Operations," and Chapter 11, "Efficient Resource Planning" for the details involving the preparation of effective supply plans at both the aggregate and detailed levels.

Production

The production process executes the supply plan to produce the service or product. Nonetheless, the production process must be integrated with the processes that supply the inputs, establish the demands, and deliver the product to the customers. For example, while customers can always shop for standardized Dell computer packages at retail stores like Best Buy and Walmart, order placement, buying, production, and logistics processes are tightly linked at Dell when a customized machine is being ordered directly from the computer manufacturer. Dell's supply chain is designed to support an assemble-to-order strategy, thereby providing speedy service with minimal inventories.

Integrating the supply-facing and customer-facing processes to the production process is as important to service firms as it is to manufacturing firms. The best firms tightly link their production process to suppliers as well as customers.

Logistics

A key aspect of order fulfillment is the logistics process, which delivers the product or service to the customer. Five important decisions determine the design and implementation of logistics processes: (1) degree of ownership, (2) facility location, (3) mode selection, (4) capacity level, and (5) amount of cross-docking.

- *Ownership.* The firm has the most control over the logistics process if it owns and operates it, thereby becoming a *private carrier.* Although this approach may help to better achieve the firm's competitive priorities, the cost of equipment, labor, facilities, and maintenance could be high. The firm could instead leave the distribution to a *third-party logistics provider* (3PL), negotiating with the carrier for specific services. Those services could involve taking over a major portion of the order fulfillment process. 3PLs typically provide integrated services, from transportation and packaging services to warehousing and inventory management, for corporate clients that need to get their products to market. They can help with the design of a client's supply chain and facilitate the flow of information up and down the supply chain.
- *Facility Location.* A critical decision affecting the effectiveness of supply chains is the location of facilities that serve as points of service, storage, or manufacture. Chapter 13, "Supply Chains and Logistics," provides a complete discussion of facility location choices.
- *Mode Selection.* The five basic modes of transportation are (1) truck, (2) train, (3) ship, (4) pipeline, and (5) airplane. The drivers for the selection should be the firm's competitive priorities. Trucks provide the greatest flexibility because they can go wherever roads go. Transit times are good, and rates are usually better than trains for small quantities and short distances. Rail transportation can move large quantities cheaply; however, the transit times are long and often variable. Water transportation provides high capacity and low costs and is necessary for overseas shipments of bulky items; however, the transit times are slow, and highway or rail transportation is often needed to get the product to its ultimate destination. Pipeline transportation is highly specialized and is used for liquids, gases, or solids in slurry form. Although it has limited geographical flexibility, transporting via pipeline requires no packaging, and the operating costs per mile are low. Finally, air transportation is the fastest and most costly mode per mile. Nonetheless, getting a product to the customer fast using air transportation may actually reduce total costs when the costs of inventory and warehouse handling are considered. The cost of the funds tied up in some in-transit inventories can be considerable. Firms can also use mixed modal transportation, whereby a given shipment may combine two or more different modes. For example, containers can be carried by trucks, trains, or ships over different portions of their transit and can often give the best tradeoffs between cost and delivery times.

Bkp/Shutterstock

The Trans Alaska Pipeline System traverses 800 miles from the North Slope of Alaska to the northern most ice-free port of Valdez, Alaska. The pipeline is 48 inches in diameter, has 11 pump stations, and has a maximum throughput of 2 million barrels per day.

- *Capacity.* The performance of a logistics process is directly linked to its capacity. The ownership decision and the modal selection decision are often intertwined because the question of how much capacity is needed must be resolved. If ownership of the equipment and facilities is under consideration, capital costs as well as variable operating costs must be weighed against the costs of obtaining the logistics services from a supplier. Making things more difficult is the fact that the requirements for the logistics process are rarely known with certainty. In such cases, management can use the *expected value decision rule* to evaluate capacity alternatives. The expected value of an alternative is calculated as follows:

  Expected value of an alternative = (probability of a level of demand occurring) multiplied by (payoff for using the alternative if that level of demand materialized) summed over all possible levels of demand.

  See Supplement A, "Decision Making Models," for details on this approach. Example 14.3 demonstrates the use of the expected value decision rule for analyzing truck capacity.

EXAMPLE 14.3 Using the Expected Value Decision Rule for Truck Capacity

Tower Distributors provides logistical services to local manufacturers. Tower picks up products from the manufacturers, takes them to its distribution center, and then assembles shipments to retailers in the region. Tower needs to build a new distribution center; consequently, it needs to make a decision on how many trucks to use. The monthly amortized capital cost of ownership is $2,100 per truck. Operating variable costs are $1 per mile for each truck owned by Tower. If capacity is exceeded in any month, Tower can rent trucks at $2 per mile. Each truck Tower owns can be used 10,000 miles per month. The requirements for the trucks, however, are uncertain. Managers have estimated the following probabilities for several possible demand levels and corresponding fleet sizes.

Requirements (miles/month)	100,000	150,000	200,000	250,000
Fleet Size (trucks)	10	15	20	25
Probability	0.2	0.3	0.4	0.1

Notice that the sum of the probabilities must equal 1.0. If Tower Distributors wants to minimize the expected cost of operations, how many trucks should it use?

SOLUTION

We use the expected value decision rule to evaluate the alternative fleet sizes where we want to minimize the expected monthly cost. To begin, the monthly cost, C, must be determined for each possible combination of fleet size and requirements. The cost will depend on whether additional capacity must be rented for the month. For example, consider the *10 truck fleet size* alternative, which represents a capacity of 100,000 miles per month. C = monthly capital cost of ownership + variable operating cost per month + rental costs if needed:

$$\begin{aligned}
C\,(100{,}000\text{ miles/month}) &= (\$2{,}100/\text{truck})(10\text{ trucks}) + (\$1/\text{mile})(100{,}000\text{ miles}) = \$121{,}000\\
C\,(150{,}000\text{ miles/month}) &= (\$2{,}100/\text{truck})(10\text{ trucks}) + (\$1/\text{mile})(100{,}000\text{ miles})\\
&\quad + (\$2\text{ rent/mile})(150{,}000\text{ miles} - 100{,}000\text{ miles}) = \$221{,}000\\
C\,(200{,}000\text{ miles/month}) &= (\$2{,}100/\text{truck})(10\text{ trucks}) + (\$1/\text{mile})(100{,}000\text{ miles})\\
&\quad + (\$2\text{ rent/mile})(200{,}000\text{ miles} - 100{,}000\text{ miles}) = \$321{,}000\\
C\,(250{,}000\text{ miles/month}) &= (\$2{,}100/\text{truck})(10\text{ trucks}) + (\$1/\text{mile})(100{,}000\text{ miles})\\
&\quad + (\$2\text{ rent/mile})(250{,}000\text{ miles} - 100{,}000\text{ miles}) = \$421{,}000
\end{aligned}$$

Next, calculate the expected value for the *10 truck fleet size* alternative as follows:

$$\textit{Expected Value}\,(10\text{ trucks}) = 0.2(\$121{,}000) + 0.3(\$221{,}000) + 0.4(\$321{,}000) + 0.1(\$421{,}000) = \$261{,}000$$

Using similar logic, we can calculate the expected costs for each of the other fleet-size options:

$$\begin{aligned}
\textit{Expected Value}\,(15\text{ trucks}) &= 0.2(\$131{,}500) + 0.3(\$181{,}500) + 0.4(\$281{,}500) + 0.1(\$381{,}500) = \$231{,}500\\
\textit{Expected Value}\,(20\text{ trucks}) &= 0.2(\$142{,}000) + 0.3(\$192{,}000) + 0.4(\$242{,}000) + 0.1(\$342{,}000) = \$217{,}000\\
\textit{Expected Value}\,(25\text{ trucks}) &= 0.2(\$152{,}500) + 0.3(\$202{,}500) + 0.4(\$252{,}500) + 0.1(\$302{,}500) = \$222{,}500
\end{aligned}$$

Using the expected value decision rule, Tower Distributors should use a fleet of 20 trucks.

DECISION POINT

The fleet size of 20 trucks means that Tower will have enough capacity to handle 90 percent of its requirements (sum of the probabilities for 100,000 miles, 150,000 miles, and 200,000 miles). Further, there will be a 50 percent chance that it will have excess capacity (sum of the probabilities for 100,000 miles and 150,000 miles). While the decision to invest in 20 trucks will minimize expected costs, it will also provide slack capacity 50 percent of the time, which is reflective of the relatively high cost for being short of capacity.

cross-docking

The packing of products on incoming shipments so that they can be easily sorted at intermediate warehouses for outgoing shipments based on their final destinations.

- *Cross-Docking.* Low-cost operations and delivery speed can be enhanced with a technique called **cross-docking**, which is the packing of products on incoming shipments so that they can be easily sorted at intermediate warehouses for outgoing shipments based on their final destinations; the items are carried from the incoming-vehicle docking point to the outgoing-vehicle docking point without being stored in inventory at the warehouse. The warehouse becomes a short-term staging area for organizing efficient shipments to customers. The benefits of cross-docking include reductions in inventory investment, storage space requirements, handling costs, and lead times, as well as increased inventory turnover and accelerated cash flow. Management must decide where cross-docking operations are best placed, given the overall flow of items and their destinations.

Customer Relationship Process

The customer relationship process addresses the interface between the firm and its customers downstream in the supply chain. The purpose of the customer relationship process, which supports *customer relationship management (CRM)* programs, is to identify, attract, and build relationships with customers and to facilitate the transmission and tracking of orders. Key nested processes include the marketing, order placement, and customer service processes.

Marketing

The marketing process focuses on such issues as determining the customers to target, how to target them, what services or products to offer and how to price them, and how to manage promotional campaigns. In this regard, **electronic commerce (e-commerce)**, which is the application of information and communication technology anywhere along the supply chain of business processes, has had a huge impact up and down the supply chain. There are two e-commerce technologies that relate to the marketing process: (1) business-to-consumer (B2C) and (2) business-to-business (B2B) systems.

electronic commerce (e-commerce)
The application of information and communication technology anywhere along the supply chain of business processes.

Business-to-Consumer Systems Business-to-consumer (B2C) systems, which allow customers to transact business over the Internet, are commonplace. B2C e-commerce offers a new distribution channel for businesses, and consumers can avoid crowded department stores with long checkout lines and parking-space shortages. Many of the advantages of e-commerce were first exploited by retail "e-businesses," such as Amazon.com, E*TRADE, and Autobytel. These three companies created Internet versions of traditional bookstores, brokerage firms, and auto dealerships. The Internet has changed operations, processes, and cost structures for even traditional retailers, and the overall growth in its usage has been dramatic. Today, anyone with an Internet connection can open a store in cyberspace. Even well-established retailers like Walmart have a web-based shopping presence through their site-to-store program, where customers can actually shop on the Internet and pick up their order at the closest store within a few days.

Business-to-Business Systems The biggest growth, however, has been in business-to-business (B2B) e-commerce systems, or commerce between firms. In fact, business-to-business e-commerce outpaces business-to-consumer transactions, with trade between businesses making up more than 70 percent of the regular economy. These systems facilitate trade up and down the supply chain, making it easier to purchase or sell services or products. B2B systems can also help manage the flow of materials. For example, if a distributor is out of stock, the firm's central warehouse can be notified to immediately ship replenishment stock directly to the customer.

Order Placement

The order placement process involves the activities required to execute a sale, register the specifics of the order request, confirm the acceptance of the order, and track the progress of the order until it is completed. Often the firm has a sales force that visits prospective and current customers to encourage a sale.

The Internet enables firms to reengineer their order placement process to benefit both the customer and the firm. The Internet provides the following advantages for a firm's order placement process.

- *Cost Reduction.* Using the Internet can reduce the costs of processing orders because it allows for greater participation by the customer. Customers can select the services or products they want and place an order with the firm without actually talking to anyone. This approach reduces the need for call centers, which are labor intensive and often take longer to place orders.
- *Revenue Flow Increase.* A firm's Web page can allow customers to enter credit card information or purchase-order numbers as part of the order placement process. This approach reduces the time lags often associated with billing the customer or waiting for checks sent in the mail.
- *Global Access.* Another advantage the Internet provides to firms is the opportunity to accept orders 24-hours a day. Traditional brick-and-mortar firms only take orders during their normal business hours. Firms with Internet access can reduce the time it takes to satisfy customers, who can shop and purchase at any time. This access gives these firms a competitive advantage over brick-and-mortar firms.
- *Pricing Flexibility.* Firms with their services and products posted on the Web can easily change prices as the need arises, thereby avoiding the cost and delay of publishing new catalogs. Customers placing orders have current prices to consider when making their choices. From the perspective of supply chains, Dell uses this capability to control for component shortages. Because of its direct-sales approach and promotional pricing, Dell can steer customers to certain configurations of computers for which ample supplies exist.

Sherwin Crasto/Reuters/Corbis

Many firms have outsourced their customer service processes, particularly if the service can be transacted over the phone. Here Indian employees at a call center in the southern city of Bangalore, India, provide service support to international customers.

Customer Service

The customer service process helps customers with answers to questions regarding the service or product, resolves problems, and, in general, provides information to assist customers. It is an important point of contact between the firm and its customers, who may judge the firm on the basis of their experiences with this process. The age-old tradeoff between cost and quality, however, enters the picture, especially for call centers. In an effort to reduce the cost of their customer service process, many firms have opted to replace human service agents with automated systems, which often require customers to wade through an exhausting sequence of options that sometimes only lead to frustration. Other firms are using Verbots®, or "verbal robots," which are supported by sophisticated artificial intelligence. They have personalities, ask and respond to questions, and in some cases are almost indistinguishable from humans over the phone. Nonetheless, most customers and others seeking information about a service or product prefer humans. Consequently, in consideration for the cost involved, many companies have expanded their supply chain by outsourcing the customer service process to an off-shore site where labor costs are low. In this regard, India has responded in a big way to the international need for low-cost call centers. Of course, the big risk in outsourcing the customer service process, or a part of it, is that the firm loses some control over a process that has direct interface with its customers. This consideration should be carefully weighed in the final analysis.

Supply Chain Risk Management

Now that we have discussed a framework for integrated supply chains, we can return to the causes of supply chain disruptions and how integrated supply chains can mitigate the risks of poor performance from unwanted dynamics. *Supply chain risk management* focuses on managing the risks posed by any factor or event that can materially disrupt a supply chain. In this section, we address the management of operational, financial, and security risks and reveal important performance measures for tracking supply chain operations.

Operational Risks

Operational risks are threats to the effective flow of materials, services, and products in a supply chain. The following options reduce the risk for operational disruptions and also minimize the bullwhip effect in supply chains.

- *Strategic alignment*—once an appropriate design is determined for the supply chain, make sure that all partners adhere to competitive priorities that are consistent with its strategic thrust. Misalignment of priorities, goals, and objectives can cause delays or disruptions in flows in a supply chain. Internal business functions should similarly be aligned.
- *Upstream/downstream supply chain integration*—working closely with customers and suppliers in CDP and the new service or product design collaboration process improves information flows and reduces surprises from demand spikes due to promotions or supply hang-ups because of poorly designed services or products. The integration should extend as far upstream in the supply chain as possible, beyond first and second-tier suppliers.
- *Visibility*—one source of dynamics in supply chains is the lack of visibility of end-user demand by suppliers upstream in the supply chain. To facilitate planning at all levels in the supply chain, point-of-sale (POS) data, which records actual customer purchases of the final service or product, can be shared with all suppliers. RFID can also be used to track quantities of inventory throughout the supply chain.

- *Flexibility and redundancy*—develop the right level of flexibility and redundancy across the supply chain to be able to absorb disruptions and adapt to change. Seek dual sources of critical materials and components, build in adequate capacity cushions, and adjust safety stocks and inventory levels to maintain desired flows.
- *Short replenishment lead times*—improving internal processes and working with suppliers to reduce lead times allows the firm to react quickly to a change in demand levels, thereby mitigating the bullwhip effect. In addition, shorter lead times leads to smaller pipeline inventories.
- *Small order lot sizes*—working on ways to reduce the costs associated with ordering, transporting and receiving inventory throughout the supply chain will reduce order lot sizes and thereby decrease the amount of fluctuation in the size of orders in the supply chain.
- *Rationing short supplies*—when a shortage exists, customers sometimes artificially inflate their orders to protect themselves, only to cancel them later when the shortage is relieved. To counteract this behavior, suppliers can ration short supplies to customers on the basis of their past sales, rather than their current orders.
- *Everyday low pricing (EDLP)*—promotional or discount pricing encourages spikes in demand. Using a stable pricing program such as EDLP, as is done by Walmart, discourages customers from buying excess stock at discounted prices so they can offer price promotions, a practice called *forward buying.* EDLP levels the demand spikes that are driven by price fluctuations.
- *Cooperation and trustworthiness*—being cooperative in solving supply issues and providing information that can be trusted serves to reduce costs for all members of the supply chain and mitigates the deleterious effects of supply chain dynamics.

Financial Risks

Financial risks are threats to the financial flows in a supply chain, such as prices, costs, and profits. Buyers may purchase services or products at an agreed fixed price. With a commitment made at a certain price, factors outside of the control of a buyer may threaten the profitability of the buyer. For example, market conditions could cause overcapacity at the supplier or oversupply of a product such that the price of the service or product plummets, which means that the buyer's profits will be lower than they could have been, and competitors purchasing these same items at a lower price could take advantage. Alternatively, even without changes in the supply of the service or product, the exchange rate in currencies between the buyer and seller could make the agreed price more expensive for the buyer. To show the effect of fluctuations in exchange rates, consider an Italian firm that supplies cotton to a firm in the United States. The currency chosen for the transaction was the U.S. dollar (USD). A contract in July 2012 called for $100,000 in shipments per month, to end in January 2013. In July 2012, the exchange rate was 1,589 ITL/USD, or equivalently 1,589,000 lira in revenues per month for the Italian supplier. However, by the end of the contract in January 2013, the dollar depreciated relative to the Italian lira; the exchange rate fell to 1,430 ITL/USD. Because the Italian supplier had to pay all of its expenses in lira, its profits fell 10 percent even though actual operating costs did not change. A similar situation can occur when service or product prices change during a supply contract because of market conditions.

How can financial risks in a supply chain be managed? One way is to reduce unnecessary costs in supply chain operations, both upstream and downstream, which we have already discussed in this text. This approach provides some protection against cost increases due to operational issues or exchange rates. Another way is to use a new low-cost source of supply, also known as *low-cost hopping*, which could benefit a firm in the short run. However, it is not conducive to effective supply chain integration over the long term. Perhaps the most often used approach to protect against financial risks is called **hedging**, which is a supply chain risk management strategy used in limiting or offsetting the probability of loss from fluctuations in the prices of commodities or currencies. In effect, hedging is a transfer of risk without buying insurance policies. One way to hedge in a supply chain is to take advantage of the flexibility in operations to reallocate production across facilities in different regions of the world to improve financial flows. This approach, referred to as *production shifting,* moves the production of products to countries where exchange rates or commodity prices are favorable. Production facilities must be flexible enough to change their production assignments, which could entail a different mix of products and shipping schedules.

hedging
A supply chain risk management strategy used in limiting or offsetting the probability of loss from fluctuations in the prices of commodities or currencies.

Another way of hedging is to use a **futures contract**, which is a contractual agreement, generally made on the trading floor of a futures exchange, to buy or sell a particular commodity or financial instrument at a predetermined price in the future. Just like the price of blueberries at a grocery store, the prices of commodities such as metals and oil or currencies change on a weekly or daily basis. If the price goes up, the *buyer* of the futures contract makes money because he gets the product at the agreed-upon price and can now sell it at today's higher market price. If the price goes down, the futures *seller* makes money because he can buy the item at today's lower price and sell it to the futures buyer at the higher

futures contract
A contractual agreement, generally made on the trading floor of a futures exchange, to buy or sell a particular commodity or financial instrument at a pre-determined price in the future.

agreed-upon price. Often, the commodity is not actually delivered to the buyer of a futures contract. To fulfill the contract, the seller of the futures contract only has to show proof that the item is at the warehouse; the contract can be settled between the two parties by paying the cash difference.[1]

The mechanics of setting up a futures contract is beyond the scope of this text; however, a simple example can demonstrate its use in a supply chain. Suppose that Action Pro, a manufacturer of cotton sporting apparel, wants to secure its supply of cotton for the next year. The price of cotton has been volatile because of global stockpiling by large Asian manufacturers. Action Pro is not interested in speculation and only wants to break even with a hedge against future cotton prices. It is now December, currency exchange rates have been stable, and the market price for cotton is $70 per 100 pounds (CWT). If the cotton price stayed at $70 Action Pro could make a reasonable profit; however, the cotton supplier is not willing to accept a fixed price because of the possibility of a rise in global cotton prices due to the Asian activity. Consequently, Action Pro entered into a contract with the supplier for 100,000 pounds of cotton per month starting in January at market prices. To counter the risk of higher cotton prices, Action Pro entered into a futures contract with a financial institution for 100,000 pounds of cotton per month at $70/ CWT. In this contract, Action Pro agrees to pay the financial institution $70/CWT in exchange for the institution paying Action Pro whatever the market price of cotton is each month.[2] Table 14.1 contains two snapshots that demonstrate how the hedge helped Action Pro break even with regard to cotton prices.

TABLE 14.1 HEDGING THE MARKET PRICE OF COTTON

(a) It is now January and the market price of cotton has risen to $87/CWT.

Financial Result	Physical Result
Paid for 100,000 pounds of cotton on the futures contract for January at $70/CWT.	Purchased 100,000 pounds of cotton at market price of $87/CWT for January delivery.
Sold 100,000 pounds of cotton for cash at the new price of $87/CWT.	It now costs more than budgeted to produce the cotton apparel.
Financial profit $= \$87 - \$70 = \$17/CWT$.	**Physical loss in profits relative to budget** $= \$70 - \$87 = -\$17/CWT$.

The financial profit achieved by hedging has compensated for the increased price of cotton in the physical market. This means that Action Pro has been able to maintain their budgeted target of $70/CWT for their cotton supplies.

(b) It is now June and the market price of cotton has dropped to $65/CWT.

Financial Result	Physical Result
Paid $70/CWT for 100,000 pounds of cotton on the futures contract for the month of June.	Purchased 100,000 pounds of cotton at the market price of $65/CWT for June delivery.
Sold 100,000 pounds of cotton for cash at the new price of $65/CWT.	It is now less expensive to produce the cotton apparel.
Financial loss $= \$65 - \$70 = -\$5/CWT$.	**Physical increase in profits relative to budget** $= \$70 - \$65 = \$5/CWT$.

The financial loss is balanced by the increase in physical profits. Active Pro has achieved the budgeted cost of $70/CWT.

Security Risks

Security risks are threats to a supply chain that could potentially damage stakeholders, facilities, or operations; destroy the integrity of a business; or jeopardize its continuation. The actions that form the basis of these threats are intentional and are designed to do physical or financial damage. A supply chain is *secure* when it can fend off unauthorized acts that are designed to cause intentional harm or damage to the supply chain and the materials (human and otherwise) that flow through its processes. A risk is amplified if the threat has a high probability of occurrence and a high level of severity. Firms interested in achieving a high level of supply chain security have a big job; there are many elements in a typical supply

[1] For more information about futures contracts, see Kimberly Amadeo, "What Are Commodities Futures?" **http://useconomy.about.com.**

[2] This contract is actually called a "swap," which is a form of futures contract. To keep things simple, we will ignore the fees paid to the financial institution for services.

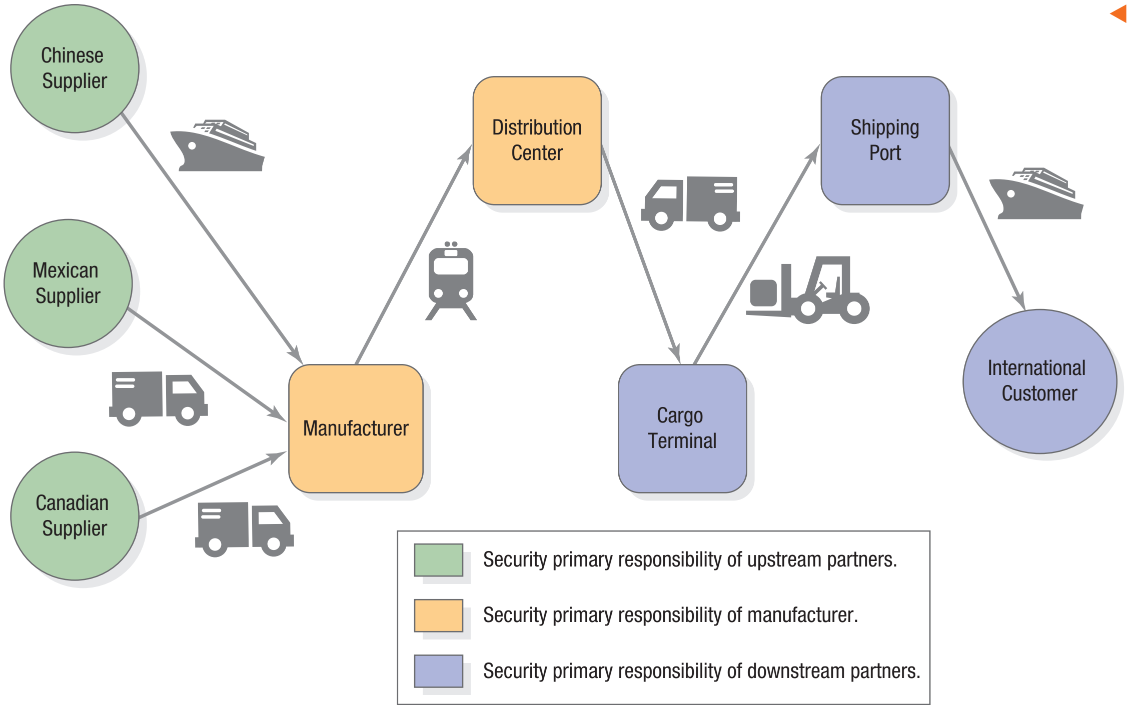


FIGURE 14.6
Elements of a Supply Chain Requiring a Security Program

chain and they are not all under the direct control of the firm. Figure 14.6 shows examples in a supply chain where security programs are needed.

Primary security responsibility shifts from suppliers, to the manufacturer, to downstream partners, and ultimately to the customer as the goods flow through the supply chain. Security programs should assess the severity of the threats, such as terrorism, cargo theft, hijacking, drug or contraband smuggling, undeclared hazardous goods, and government instability. These programs should also assess how vulnerable the supply chain is regarding procedures for security, physical access controls, container and trailer security, and information technology security, for example. Finally, the consequences of a breach in security to factors such as demand volume, the firm's competitive priorities, and the impact of lost business should be assessed. As the responsibility for security is paramount and distributed among many entities in a supply chain, it is clear that the more integrated a supply chain is, the more effective security measures can be.

While security programs vary in content depending on the application, here are some typical security activities:

- *Access control.* Check IDs of all visitors, vendors, drivers, and, in general, all participants in the supply chain. Employ real-time monitored systems that document entry, exit, and movement of materials and cargo.
- *Physical security.* Conduct random facility inspections and ensure compliance to established security standards. Monitor CCTV and alarm systems that allow for immediate real-time response. Perform penetration tests and audits of compliance.
- *Shipping and receiving.* Screen and validate the contents of the cargo being shipped and received. Provide advanced notification of the contents to

Chip Somodevilla/Getty Images

Security guards check truck drivers' paperwork as they enter the Seagrit Marine Terminal in Baltimore, Maryland. The guards can check the manifest against the items in the truck to prohibit the shipment of undocumented hazardous materials, illegal weapons, or other forms of contraband.

the destination country. Use specialized packing material, unique shipping markings, and high-security seals.

- *Transportation service provider.* Ensure the security of cargo while in transit via the use of locks and tamper-proof seals. Ensure that the carrier does not make stops in security "red zones." Require GPS tracking for the tractors and trailers and regular communication with the drivers. Require notification of the use of any subcontractors and make sure they adhere to the same security requirements as the primary carrier.
- *ISO 28000.* Recognizing the need of the international community for supply chain security, the International Standards Organization has established **ISO 28000:2007**, which is a set of requirements for a supply chain security management system that includes aspects of financing, manufacturing, information systems, and the facilities for packing, storing, and transferring goods between modes of transportation and locations. Certification in ISO 28000:2007 enables firms to demonstrate their compliance with stated security management policies.

ISO 28000:2007

A set of requirements for a supply chain security management system that includes aspects of financing, manufacturing, information systems, and the facilities for packing, storing, and transferring goods between modes of transportation and locations.

Performance Measures

It is important to monitor the performance of supply chains to see where improvements can be made or to measure the impact of disruptions. Supply chain managers monitor performance by measuring costs, time, quality, and environmental impact. Table 14.2 contains examples of commonly used performance measures for three supply chain processes. Managers periodically collect data on these measures and track them to note changes in level or direction. Statistical process control charts can be used to determine whether the changes are statistically significant.

Integrated supply chains are powerful tools for achieving competitiveness along many performance measures. Currently, concerns about security and the environment are prompting supply chain managers to take a careful look at their operations and those of their suppliers. In Chapter 15, "Managing Supply Chain Sustainability," we take a look at the impact of environmental concerns on supply chains and how integrated supply chains can be used to relieve some of those concerns and still be profitable.

TABLE 14.2 SUPPLY CHAIN MEASURES FOR CORE PROCESSES

Customer Relationship	Order Fulfillment	Supplier Relationship
■ Percent of orders taken accurately ■ Time to complete the order placement process ■ Customer satisfaction with the order placement process ■ Customer's evaluation of firm's environmental stewardship ■ Percent of business lost because of supply chain disruptions	■ Percent of incomplete orders shipped ■ Percent of orders shipped on-time ■ Time to fulfill the order ■ Percent of botched services or returned items ■ Cost to produce the service or item ■ Customer satisfaction with the order fulfillment process ■ Inventory levels of work-in-process and finished goods ■ Amount of greenhouse gasses emitted into the air ■ Number of security breaches	■ Percent of suppliers' deliveries on time ■ Suppliers' lead times ■ Percent defects in services and purchased materials ■ Cost of services and purchased materials ■ Inventory levels of supplies and purchased components ■ Evaluation of suppliers' collaboration on streamlining and waste conversion ■ Amount of transfer of environmental technologies to suppliers

LEARNING GOALS IN REVIEW

Learning Goal	Guidelines for Review	MyOMLab Resources
1 Identify the major causes of disruptions in a supply chain.	See the section "Supply Chain Disruptions" pp. 565–568. Focus on understanding the causes for disruptions from external and internal sources and what it means to integrate the supply chain. Study Figure 14.1, which demonstrates the flows in a supply chain, and Figure 14.2, which shows how mild dynamics in consumer demand can result in wild fluctuations in supplier demand. Figure 14.3 shows the integrative model used in this text, while Figure 14.4 shows the SCOR model.	**Video**: Sourcing Strategy at Starwood
2 Describe the four major nested processes in the new service and product development process.	The section "New Service or Product Development Process," pp. 568–570, discusses the four nested processes and how they are linked.	

Learning Goal	Guidelines for Review	MyOMLab Resources
3 Explain the five major nested processes in the supplier relationship process and use total cost analysis and preference matrices to identify appropriate sources of supply.	See the section "Supplier Relationship Process," pp. 570–578, for a discussion of the five nested processes. Focus on the "sourcing" process, which explains the total cost model and the preference matrix approach for finding an appropriate source of supply. Study Examples 14.1 and 14.2, along with Solved Problems 1 and 2.	**OM Explorer Tutor:** A.3: Preference Matrix **OM Explorer Solver:** Preference Matrix **POM for Windows:** Preference Matrix
4 Identify the four major nested processes in the order fulfillment process and use the expected value decision rule to determine the appropriate capacity of logistic resources.	Review the section "Order Fulfillment Process," pp. 578–580, which discusses the four key nested processes. Focus on Example 14.3, which shows how to use the expected value decision rule to choose the appropriate amount of truck capacity. Solved Problem 3 shows the set up and solution to a problem involving the expected value decision rule.	**OM Explorer Tutor:** A.5: Decisions Under Risk **OM Explorer Solver:** Decision Theory **POM for Windows:** Decision Tables
5 Define the three major nested processes in the customer relationship process.	The section "Customer Relationship Process," pp. 581–582, discusses the three major nested processes and how they link together.	
6 Explain how firms can mitigate the operational, financial, and security risks in a supply chain.	See the section "Supply Chain Risk Management," pp. 582–586, for the ways firms can mitigate the operational, financial, and security risks they face. Be sure to understand the practice of hedging and how exchange rate fluctuations and commodity price changes can be dealt with. Also study Figure 14.6 to understand the complexity of managing security risks in a supply chain.	

Key Equations

Supplier Relationship Process

1. Total Annual Cost $= pD +$ Freight costs $+ (Q/2 + \bar{d}L)H +$ Administrative costs

Order Fulfillment Process

2. *Expected value of an alternative* = (probability of a level of demand occurring)(payoff for using the alternative if that level of demand materialized) summed over all possible levels of demand.

Key Terms

auction 576
bullwhip effect 567
catalog hubs 576
competitive orientation 574
concurrent engineering 570
cooperative orientation 575
cross-docking 580
early supplier involvement 574
electronic commerce (e-commerce) 581
electronic data interchange (EDI) 576
exchange 576
futures contract 583
green purchasing 572
hedging 583
ISO 28000:2007 586
presourcing 574
purchasing 570
radio frequency identification (RFID) 577
SCOR model 568
sole sourcing 576
supply chain integration 565
supply chain risk management 565
value analysis 574
vendor-managed inventories (VMI) 577

Solved Problem 1

MyOMLab Video

Eagle Electric Repair is a repair facility for several major electric appliance manufacturers. Eagle wants to find a low-cost supplier for an electric relay switch used in many appliances. The annual requirements for the relay switch (D) are 100,000 units. Eagle operates 250 days a year. The following data are available for two suppliers, Kramer and Sunrise, for the part:

Supplier	Freight Costs Shipping Quantity (Q) 2,000	10,000	Price/Unit (p)	Carrying Cost/Unit (H)	Lead Time (L) (days)	Administrative Costs
Kramer	\$30,000	\$20,000	\$5.00	\$1.00	5	\$10,000
Sunrise	\$28,000	\$18,000	\$4.90	\$0.98	9	\$11,000

Which supplier will provide the lowest annual total costs?

SOLUTION

The daily requirements for the relay switch are:

$$\bar{d} = 100{,}000/250 = 400 \text{ units.}$$

We must calculate the total annual costs for each alternative:

$$\begin{aligned}\textbf{Total annual cost} &= \textbf{Material costs} + \textbf{Freight costs} + \textbf{Inventory costs} + \textbf{Administrative costs}\\ &= pD + \text{Freight costs} + (Q/2 + \bar{d}L)H + \text{Administrative costs}\end{aligned}$$

Kramer

$Q = 2{,}000$: $(\$5.00)(100{,}000) + \$30{,}000 + (2{,}000/2 + 400(5))(\$1) + \$10{,}000 = \$543{,}000$

$Q = 10{,}000$: $(\$5.00)(100{,}000) + \$20{,}000 + (10{,}000/2 + 400(5))(\$1) + \$10{,}000 = \$537{,}000$

Sunrise

$Q = 2{,}000$: $(\$4.90)(100{,}000) + \$28{,}000 + (2{,}000/2 + 400(9))(\$0.98) + \$11{,}000 = \$533{,}508$

$Q = 10{,}000$: $(\$4.90)(100{,}000) + \$18{,}000 + (10{,}000/2 + 400(9))(\$0.98) + \$11{,}000 = \$527{,}428$

The analysis reveals that using Sunrise and a shipping quantity of 10,000 units will yield the lowest annual total costs.

Solved Problem 2

Eagle Electric Repair wants to select a supplier based on total annual cost, consistent quality, and delivery speed. The following table shows the weights management assigned to each criterion (total of 100 points) and the scores assigned to each supplier (Excellent = 5, Poor = 1).

		Scores	
Criterion	**Weight**	**Kramer**	**Sunrise**
Total annual cost	30	4	5
Consistent quality	40	3	4
Delivery speed	30	5	3

Which supplier should Eagle select given these criteria and scores?

SOLUTION

Using the preference matrix approach, the weighted scores for each supplier are:

$$\textit{Kramer:}\quad WS = (30 \times 4) + (40 \times 3) + (30 \times 5) = 390$$

$$\textit{Sunrise:}\quad WS = (30 \times 5) + (40 \times 4) + (30 \times 3) = 400$$

Based on the weighted scores, Eagle should select Sunrise even though delivery speed performance would be better with Kramer.

Solved Problem 3

Schneider Logistics Company has built a new warehouse in Columbus, Ohio, to facilitate the consolidation of freight shipments to customers in the region. George Schneider must determine how many teams of dock workers he should hire to handle the cross-docking operations and the other warehouse activities. Each team costs \$5,000 a week in wages and overhead. Extra capacity can be subcontracted at a cost of \$8,000 a team per week. Each team, whether in-house or subcontracted, can satisfy 200 labor hours of work a week. The labor hour requirements for the new facility are uncertain. Management has estimated the following probabilities for the requirements:

Requirements (hours/wk)	200	400	600
Number of teams	1	2	3
Probability	0.20	0.50	0.30

How many teams should Schneider hire?

SOLUTION

We use the expected value decision rule by first computing the cost for each option for each possible level of requirements and then using the probabilities to determine the expected value for each option. The option with the lowest expected cost is the one Schneider will implement. We demonstrate the approach using the "one team" in-house option.

One Team In-House

$$C(200) = \$5{,}000$$
$$C(400) = \$5{,}000 + \$8{,}000 = \$13{,}000$$
$$C(600) = \$5{,}000 + \$8{,}000 + \$8{,}000 = \$21{,}000$$

Expected Value

$$(\text{One Team}) = 0.20(\$5{,}000) + 0.50(\$13{,}000) + 0.30(\$21{,}000) = \$13{,}800.$$

A table of the complete results is below.

	Weekly Labor Requirements			
In-House	**200 hrs**	**400 hrs**	**600 hrs**	**Expected Value**
One team	\$5,000	\$13,000	\$21,000	\$13,800
Two teams	\$10,000	\$10,000	\$18,000	\$12,400
Three teams	\$15,000	\$15,000	\$15,000	\$15,000

Based on the expected value decision rule, Schneider should employ two teams at the warehouse.

Discussion Questions

1. Supply chain dynamics can cause excessive costs and poor customer service. Explain how the redesign of a supply chain can help to mitigate the effects of supply chain dynamics.
2. The *Coral Princess* cruise line illustrates how many goods and services can be seamlessly coordinated without the guests seeing any of the operations being performed at any given moment. This requires well coordinated operations and logistics. Define supply chain integration and illustrate how this company manages its supply chain operations while delivering a unique cruising experience to its guests.
3. Supply chain management is, among other things, about managing information flows. From the many examples provided in the chapter, describe how information flows are managed in order to improve supply chain integration.
4. We discussed the inventory and supply chain considerations such as small lot sizes, close supplier ties, and quality at the source in Chapter 6, "Designing Lean Systems." What are the implications of these principles for supply chain integration?

Problems

The OM Explorer and POM for Windows software is available to all students using the 11th edition of this textbook. Go to **http://www.pearsonglobaleditions.com/krajewski** to download these computer packages. If you purchased MyOMLab, you also have access to Active Models software and significant help in doing the following problems. Check with your instructor on how best to use these resources. In many cases, the instructor wants you to understand how to do the calculations by hand. At the least, the software provides a check on your calculations. When calculations are particularly complex and the goal is interpreting the results in making decisions, the software entirely replaces the manual calculations.

Supplier Relationship Process

1. Horizon Cellular manufactures cell phones for exclusive use in its communication network. Management must select a circuit board supplier for a new phone soon to be introduced to the market. The annual requirements are 50,000 units and Horizon's plant operates 250 days per year. The data for three suppliers are in Table 14.3.

   Which supplier and shipping quantity will provide the lowest total cost for Horizon Cellular?

TABLE 14.3 DATA FOR SUPPLIERS TO HORIZON CELLULAR

	Annual Freight Costs Shipping Quantity					
Supplier	**10,000**	**20,000**	**Price/Unit**	**Annual Holding Cost/Unit**	**Lead Time (Days)**	**Annual Administrative Cost**
Abbott	$10,000	$7,000	$30	$6.00	4	$10,000
Baker	$12,000	$9,000	$28	$5.60	7	$12,000
Carpenter	$9,000	$6,500	$31	$6.20	3	$9,000

2. Eight Flags operates several amusement parks in the Midwest. The company stocks machine oil to service the machinery for the many rides at the parks. Eight Flags needs 30,000 gallons of oil annually; the parks operate 50 weeks a year. Management is unsatisfied with the current supplier of oil and has obtained two bids from other suppliers. The data are contained in Table 14.4.

Which supplier and which shipping quantity will provide the lowest costs for Eight Flags?

TABLE 14.4 DATA FOR SUPPLIERS TO EIGHT FLAGS

	Annual Freight Costs Shipping Quantity						
Supplier	**5,000**	**10,000**	**15,000**	**Price/Unit**	**Annual Holding Cost/Unit**	**Lead Time (wks)**	**Annual Administrative Cost**
Sharps	$5,000	$2,600	$2,000	$4.00	$0.80	4	$4,000
Winkler	$5,500	$3,200	$2,900	$3.80	$0.76	6	$5,000

3. The Bennet Company purchases one of its essential raw materials from three suppliers. Bennet's current policy is to distribute purchases equally among the three. The owner's son, Benjamin Bennet, just graduated from a business college. He proposes that these suppliers be rated (high numbers mean a good performance) on six performance criteria weighted as shown in the table. A total score hurdle of 0.60 is proposed to screen suppliers. Purchasing policy would be revised to order raw materials from suppliers with performance scores greater than the total score hurdle, in proportion to their performance rating scores.

		Rating		
Performance Criterion	**Weight**	**Supplier A**	**Supplier B**	**Supplier C**
1. Price	0.3	0.7	0.8	0.6
2. Quality	0.2	0.3	0.5	0.4
3. Delivery	0.2	0.7	0.5	0.4
4. Production facilities	0.1	0.8	0.6	0.5
5. Environmental protection	0.1	0.8	0.7	0.9
6. Financial position	0.1	0.9	0.8	0.7

a. Use a preference matrix to calculate the total weighted score for each supplier.

b. Which supplier(s) survived the total score hurdle? Under the younger Bennet's proposed policy, what proportion of orders would each supplier receive?

c. What advantages does the proposed policy have over the current policy?

4. Beagle Clothiers uses a weighted score for the evaluation and selection of its suppliers of trendy fashion garments. Each supplier is rated on a 10-point scale (10 = highest) for four different criteria: price, quality, delivery, and flexibility (to accommodate changes in quantity and timing). Because of the volatility of the business in which Beagle operates, flexibility is given twice the weight of each of the other three criteria, which are equally weighted. The table below shows the scores for three potential suppliers for the four performance criteria. Based on the highest weighted score, which supplier should be selected?

Criteria	**Supplier A**	**Supplier B**	**Supplier C**
Price	7	5	6
Quality	6	9	8
Delivery	9	7	5
Flexibility	5	6	9

5. D Bradley Solutions and Alexander Limited are two well-established suppliers of inexpensive tools. Weekend Projects is a national chain of retail outlets that caters to the occasional fixer-upper who would prefer to get the job done fast rather that investing in a well-appointed tool box. Weekend Projects wants to find a supplier for a particular tool set that promises to be a big seller. Expected annual sales are 100,000 units. Weekend's warehouses operate 50 weeks a year. Management collected data on the two suppliers, which are contained in the first table.

a. Which of the two suppliers would provide the lowest annual cost to Weekend Projects? What shipping quantity would you suggest?

D = Difficult Problem

b. Before management could make a decision, another option became available. Zelda Tools offered the tool set for only $8.00; however, the lead time is longer than the other two suppliers. Zelda is a new supplier and has not been in the industry very long. Additional data for Zelda are in the second table. Management has begun to assess the administrative costs to manage the contract with Zelda. What is the lowest level of administrative costs at which Weekend Projects would be indifferent between using Zelda versus the option you chose in part (a)?

	Freight Costs Shipping Quantity						
Supplier	**10,000**	**25,000**	**50,000**	**Price/Unit**	**Annual Holding Cost/Unit**	**Lead Time (wks)**	**Annual Administrative Cost**
Bradley	$40,000	$28,000	$19,000	$8.10	$1.62	6	$10,000
Alexander	$30,000	$26,000	$19,000	$8.10	$1.62	7	$15,000

	Freight Costs Shipping Quantity					
Supplier	**10,000**	**25,000**	**50,000**	**Price/Unit**	**Annual Holding Cost/Unit**	**Lead Time (wks)**
Zelda	$35,000	$27,000	$19,000	$8.00	$1.60	8

6. D Wanda Lux must select a supplier for a plastic bottle and proprietary dispenser for its new hair shampoo. Three suppliers have placed bids; at Wanda's request, all bids are for a shipping quantity of 20,000 bottles with annual requirements of 40,000 units. Wanda's factory operates 250 days a year. The first table (below) shows each supplier's price, estimated annual freight costs, and current lead times; management has added estimates for holding costs and administrative oversight costs for each supplier. Beyond costs, however, Wanda has three other criteria considered important in the selection of a supplier. The second table (see below) shows all the criteria, their weights, and the scores for all of them except total costs, where a score of 1 indicates "poor" and 10 indicates "superior." Because all three suppliers have done business with Wanda Lux before, management will assign a score of "10" to the supplier with the lowest total annual cost, a score of "8.5" for the next lowest cost, and a score of "7.0" for the worst cost of the three.

a. Which of the three suppliers will provide the lowest annual cost to Wanda Lux?

b. Given Wanda's criteria and weighting system, which supplier should Wanda award the contract to?

Supplier	Freight Costs	Price/Unit	Annual Holding Cost/Unit	Lead Time (days)	Annual Administrative Cost
Dover Plastics	$4,000	$5.05	$1.01	14	$5,000
Evan & Sons	$3,500	$5.15	$1.03	18	$4,000
Farley, Inc.	$4,500	$5.10	$1.02	17	$3,000

		Rating		
Criteria	**Weight**	**Dover**	**Evan**	**Farley**
Total Cost	30	?	?	?
Consistent Quality	30	7	8	9
On-Time Delivery	20	7	7	9
Environment	20	9	9	8

7. D Adelie Enterprises is exploring a new service to provide weekly delivery of grocery items to homes in the greater Greenwood area. The company's customers place Web-based orders and Adelie's team assembles and delivers the orders in specially designed cardboard boxes. Management, interested in locating a supplier that can provide boxes cheaply and efficiently, has discovered that each potential supplier's ability to satisfy the company's requirements is influenced by the level of demand. The following table provides Adelie's vendor selection criteria, criterion weights, and rankings (1–10 with 10 being the highest) under the assumption that low, moderate, or high demand is generated for their service.

D = **Difficult Problem**

SUPPLIER RATING UNDER LOW, MODERATE, AND HIGH LEVELS OF DEMAND

		Local Supplier			National Supplier			International Supplier		
	Weight	**Low**	**Moderate**	**High**	**Low**	**Moderate**	**High**	**Low**	**Moderate**	**High**
Product Quality	0.35	8	6	5	7	7	7	6	6	6
Delivery Speed	0.15	9	7	3	6	6	6	4	5	7
Product Price	0.25	5	5	3	5	7	9	7	7	9
Environmental Impact	0.25	9	9	9	7	7	7	8	8	8

a. Which supplier should be selected if there is low demand for Adelie's new service? Which supplier should be selected under moderate demand assumptions? Under high demand assumptions?

b. Which supplier is selected if Adelie evaluates each alternative using a Maximin decision criterion (see Supplement A, "Decision Making Models")?

c. Which supplier achieves the highest expected ranking if the probability of low demand is 35 percent, moderate demand is 45 percent, and high demand is 20 percent?

8. (D) Adelie Enterprises (from Problem 7) has decided to drop the international supplier from consideration. Furthermore, Adelie has decided to order boxes in lots of 10,000 to optimize the use of available storage space at its distribution facility. To more completely consider the cost/volume tradeoffs associated with selecting the local or national supplier, management has collected the following data. Adelie services its customers 250 days per year.

	Demand Level	Demand	Price/unit	Freight Cost/1,000	Carrying Cost/unit	Lead Time (days)	Administrative costs
Local Supplier	Low	50,000	$1.25	$20.00	$0.10	1	$15,000.00
	Moderate	100,000	$1.25	$20.00	$0.10	1	$15,000.00
	High	250,000	$1.25	$20.00	$0.10	1	$15,000.00
National Supplier	Low	50,000	$1.35	$120.00	$0.10	15	$12,500.00
	Moderate	100,000	$1.25	$120.00	$0.10	15	$12,500.00
	High	250,000	$1.00	$120.00	$0.10	15	$12,500.00

a. On purely a total cost basis, which supplier should be selected if there is low demand for Adelie's new service; which supplier should be selected under moderate demand assumptions; and which supplier should be selected under high demand?

b. Which supplier achieves the lowest expected cost if the probability of low demand is 35 percent, moderate demand is 45 percent, and high demand is 20 percent?

Order Fulfillment Process

9. Wingman Distributing Company is expanding its supply chain to include a new distribution hub in South Bend. A key decision involves the number of trucks for the facility. The particular model of truck Wingman is considering can be used 5,000 miles a month and will cost $900 a month in capital costs. In addition, each mile a truck is used costs $0.90 for maintenance. A local truck rental firm will rent trucks at a cost of $1.80 per mile. Given the distribution of likely requirements for trucks, management has come up with three alternatives to consider as shown in the table:

Monthly requirements (miles)	50,000	100,000	150,000
Probability	0.20	0.50	0.30
Fleet size (trucks)	10	20	30

Which fleet size will yield the lowest expected monthly costs for Wingman?

10. Sanchez Trucking has been experiencing delays at its warehouse operations. Management hired a consultant to find out why service deliveries to local businesses have taken longer than they should. The consultant narrowed down the problem to the number of work crews loading and unloading trucks. Each crew consists of six employees who work as a team on a variety of tasks; each employee works a full 40 hours a week. However, costs are also a concern. The consultant advised management that they could supplement work crews with short-term employees, at a higher cost, to cover unexpected needs on a weekly basis. Each work crew permanently hired by Sanchez costs $3,500 per week in wages and benefits, while a crew of short-term employees costs $5,500 per week. Complicating the decision is the fact that the weekly hourly requirements for work crews is uncertain because of the volatility in the number of deliveries to be made. Deliberating with management, the consultant arrived at the following data:

D = **Difficult Problem**

Requirements (labor hours)	960	1,200	1,440	1,680
Probability	0.1	0.5	0.3	0.1
Number of Crews	4	5	6	7

If the consultant wants to offer a solution that minimizes the expected weekly costs for Sanchez, how many work crews should Sanchez have on its permanent payroll?

11. Acadia Logistics anticipates that it will need more distribution center space to accommodate what it believes will be a significant increase in demand for its final-mile services. Acadia could either lease public warehouse space to cover all levels of demand or construct its own distribution center to meet a specified level of demand, and then use public warehousing to cover the rest. The yearly cost of building and operating its own facility, including the amortized cost of construction, is $12.00 per square foot. The yearly cost of leasing public warehouse space is $20.00 per square foot. The expected demand requirements follow:

Requirements (in sq. ft)	200,000	300,000	400,000	500,000
Probability	0.4	0.3	0.2	0.1

a. Calculate the expected value of leasing public warehouse space as required by demand.

b. Calculate the expected value of building a 200,000-square-foot distribution center and leasing public warehouse space as required if demand exceeds the need for 200,000 square feet of space.

c. Calculate the expected value of building a 300,000-square-foot distribution center and leasing public warehouse space as required if demand exceeds the need for 300,000 square feet of space.

d. Calculate the expected value of building a 400,000-square-foot distribution center and leasing public warehouse space as required if demand exceeds the need for 400,000 square feet of space.

e. Calculate the expected value of building a 500,000-square-foot distribution.

f. Which of the above decisions provides the minimized expected value?

12. Transworld Deliveries is expanding its contract home delivery service into the Northeastern United States. The company anticipates that to accommodate this expansion it will need between 25 and 40 staffed delivery vehicles. Transworld is currently moving 25 of its own vehicles, with drivers, into the Northeast. The daily cost of operating its own fleet is $820 per vehicle, while the daily cost of leasing a vehicle and driver is expected to be $1,200 per vehicle. The expected demand requirements follow:

Requirements (in vehicles)	25	30	35	40
Probability	0.25	0.25	0.25	0.25

Using an expected value approach, should Transworld purchase additional vehicles and hire additional drivers? If so, how many would you recommend?

Supply Chain Risk Management

13. Eastmark Electrical Equipment Manufacturers needs to secure its supply of copper for the next year. The price of copper is extremely volatile because of huge month-to-month variation in demand. Eastmark wants to break even with a hedge against future copper prices. Currently, the market price for copper is reasonably low at $3.25 per pound or $325 (CWT). Eastmark has entered into a contract with the supplier for 500,000 pounds of copper per month starting in January at market prices. Eastmark has also entered into a futures contract with a financial institution for 500,000 pounds per month at $3.25 per pound. CWT (hundredweight) is equal to 100 pounds in the United States.

a. Calculate the one month financial and the physical results if the market price of copper has risen to $4.50 per pound.

b. Calculate the one month financial and the physical results if the market price of copper has fallen to $3.00 per pound.

14. Refer to Problem 13 regarding Eastmark Electrical Equipment Manufacturers. Suppose the futures contact is still in force in February.

a. However, assume the firm has just lost a key client's business and only purchases 400,000 pounds of copper.

- **i.** Calculate the one month financial and the physical results if the market price of copper has risen to $4.50 per pound. Calculate only the financial impact of copper transactions and disregard the loss of revenue due to business loss.
- **ii.** Calculate the one month financial and the physical results if the market price of copper has fallen to $3.00 per pound. Calculate only the financial impact of copper transactions and disregard the loss of revenue due to business loss.

b. Now assume the firm has just received a new client's business and must purchase 800,000 pounds of copper.

- **i.** Calculate the one month financial and the physical results if the market price of copper has risen to $4.50 per pound. Calculate only the financial impact of copper transactions and disregard the loss of revenue due to business loss.
- **ii.** Calculate the one month financial and the physical results if the market price of copper has fallen to $3.00 per pound. Calculate only the financial impact of copper transactions and disregard the loss of revenue due to business loss.

VIDEO CASE Sourcing Strategy at Starwood

Bath towels. Televisions. Fresh produce. Uniforms. On the surface, these items may not appear to have any relationship to each other. Sure, they exist in most households, even though they were probably bought independently of one another. Yet to the supply chain manager employed in the hospitality industry, they not only have a relationship, but their purchase can be critical to gaining a competitive advantage.

Just ask Paul Davis, vice president of strategic sourcing for Starwood's North American operations. With hundreds of hotels and resorts in the United States, Canada, and the Caribbean, Davis's goal is to create the hospitality industry's best supply chain organization. The items procured within his organization not only include replenishable goods such as fresh produce and food items but also extend to the sourcing of national contracts for nonperishable goods such as bath towels, electronics, staff apparel, energy, and contract services.

It is easy to confuse supply chain processes with the routine procurement of goods and services. Starwood's supply chain certainly does include contracting, but it is much more: It consists of the customer relationship, order fulfillment, and supplier relationship processes. Strong linkages exist among the company's upstream suppliers of services, materials, and information and the customers of Starwood's hotels and resorts. If the upstream relationships are not carefully managed, downstream delivery of consistency, quality, and value to Starwood's guests may suffer. As a result, significant effort is placed on the nested processes within the supplier relationship process such as design collaboration, sourcing, negotiation, contracting, and information exchange.

Any number of events will trigger the involvement of Paul Davis's supply chain team:

- Existing contracts expire.
- Individual hotel brands seek new products.
- Hotel property design teams generate ideas.
- New categories of products emerge and need evaluation.
- A particular hotel needs help with a local service contract.

When a product or service needs to be sourced, the specifications are driven by internal customers such as restaurant chefs, housekeeping, and maintenance. If the product or service does not already exist, domestic and international suppliers that might be able to create the item are researched, as are regional and local vendors. Sometimes, sourcing an existing item simply means renewing an agreement with a current supplier. Still other situations demand creating a new category that has not been sourced before or using a third party to help locate sources.

Due diligence is always performed by sending potential suppliers a "request for information" in either paper or electronic form. The responses returned by the suppliers are entered into a database and help Starwood to prequalify the suppliers. A good match is sought, requiring the suppliers to meet minimum requirements for financial viability, quality, scope of operations, references, and legal risk avoidance. With a suitable potential supplier candidate pool, Starwood then takes one of two paths. The first one is to conduct a reverse auction where preselected vendors bid against each other. This method is used with shorter-term contracts on commodity items that have low external customer visibility. Kitchen uniforms, hotel room door keys, and paint are sourced this way. The second option is to send out a request for proposals (RFP), which requires the vendor to put its best terms forward at the outset for consideration.

After review by the supply chain team, the vendor winning the auction or emerging from the RFP review activity as the best fit is engaged in negotiations. Throughout the supplier relationship building process, Starwood gets to know the vendors, but it becomes much more personal at this point as both parties move toward concluding their contract negotiations.

Starwood maintains a cooperative orientation toward its supplier relationships, building a partnership to maximize value for each party to ensure that each side is comfortable with the price, quality, and delivery requirements it has agreed upon in the contract negotiation process. When contract negotiations are complete, the different brands are notified and the buying and information exchange processes begin.

At this point, you might think the job of the supply chain team is done. Yet managing the existing supplier relationship after the contract ink dries is perhaps the most challenging task of all. The contract involving sourcing of bed linens and terrycloth items is a perfect example. Not long after the contract was finalized, an alternate supplier approached Starwood with an offer to supply comparable quality goods at a much lower cost. Supply chain managers had a choice to make: continue to work with the existing supplier or buy out the current supplier's contract and begin sourcing with the new one.

QUESTIONS

1. Should Starwood maintain a cooperative orientation or a competitive orientation with its suppliers for the kind of items described here?
2. What types of information should Starwood exchange with its bed linens and terrycloth supplier? What does Starwood risk by sharing too much information?
3. How would you approach the sourcing of bed linens and terrycloth items? That is, would you use a reverse auction or request for proposal? Under what circumstances would you change suppliers?
4. In addition to performing value analysis on the services its properties offer, Starwood evaluates the performance of its suppliers against contract metrics. Using the bed linens and terrycloth supplier as an example, describe some of the metrics Starwood should use.

CASE HassiaWaters International

Background

HassiaWaters International is the fourth-largest soft drink manufacturer in Germany; it exports its high-end products throughout Europe, notably to Benelux, for high-end restaurants. Its history can be traced back to 1864, when Johann Philipp Wilhelm Hinkel started selling water from its well in Bad Vilbel, which is one of the most famous spa towns not only in Germany, but also in all of Europe. However, the company laid the foundation of its future success when Johann's son, Fritz, took over the operations in 1898. Its line of products includes premium mineral water, known for promoting well-being, and other beverages. Their customers are restaurants, bars, and retailers who display high-end mineral water, including Carrefour.

The Hinkel family still runs the group and now employs more than 1,300 people across seven locations between the bottling plants and the warehouses. HassiaWaters was quick to understand the importance of a dynamic supply chain to keep its inventory costs down and to deliver high quality products within a short period of time to a wide array of customers.

The Heart of Hassia's Supply Chain: The Warehouse

Hassia has a 30,000 square meter warehouse in Bad Vilbel, less than half a block from the bottling plant. Complete pallets circulate from the bottling plant to the warehouse via an ingenuous underground monorail. The company understands that the key element of its supply chain is its warehousing system. With appropriate systems, inventory can be kept to a minimum and orders are met within a few hours. The warehouse involves no paperwork and is fully integrated into its enterprise resource planning (ERP) system (See Chapter 11: "Efficient Resource Planning" for more discussions on ERP). ERP systems integrate all the organization's decision elements, including inventory levels, demand for specific product lines, and replenishing lead times. All these variables are monitored thanks to the system, which helps in fine-tuning stock levels and increases productivity. Sixteen different products are stored in 13,000 different pallet locations and there are up to 12,000 pallet movements per day. The waters are divided in three product lines—the Rosbacher, which generates volume; the Lichtenauer, which represents health, and LIZ, which has a high-end positioning with an elegant bottle design. Bottles are stored in crates assembled in pallets.

Information System Management

Pallets are stacked up to 7 meters high. All forklifts are connected to the warehouse management system. They belong to a "pool" and are assigned jobs according to their location in the warehouse and the order priority. When a driver is in front of the storage area, they confirm on a touchscreen that they are ready to pick the order. The system checks if it is the right location; it denies the order if the driver is not in the right position. Forklifts are located with the help of radio-frequency identification (RFID) system and their odometer. Once a driver confirms they have dropped off an order, another one comes in immediately. To minimize empty runs, when an employee has just completed a storage order they can retrieve a pallet to supply a consignment.

Inventory is managed by an ERP system with adjustable parameters. When a consignment reaches the minimum stock level, an order is placed to the bottling plant. The entire system works in real time and warehouse supervisors monitor each employee's position using a 3D warehouse simulation software. Different colors on a screen are assigned to the pallet storage locations. Green and red are used to indicate whether a pallet can be taken or not. Pallets can be reserved for upcoming larger orders, hence the red color. On the system, by hovering over a modelized storage location, the production date, product type, and stock levels appear. All pallets are identified with barcodes.

Loading and Shipping

Mixed pallets are also managed for smaller orders automatically by the system, according to demand. The special design of the crates allows for the storage of mineral water as well as other beverages. To efficiently deliver personalized shipments—like 1,000 units of sparkling water, 2,000 units of apple juice, and 1,500 units of orange juice—the system orders forklifts to retrieve several different pallets. The contents of the pallets are then broken down and re-assembled in mixed products pallets. Mixed orders are labeled, sent down to the loading area by an electrical conveyor belt, and are automatically scanned. Trucks are sideloaded to reduce the loading time in each bay and to allow more forklift movements, rather than loading from the narrower back of the truck.

The loading is also managed by the system and trucks are modeled on visualization screens. The system optimizes truck loads according to their volume. Different color codes are used to identify different pallet dimensions. When a forklift driver receives an order to pick a pallet, their screen shows its location and also where in the truck it will have to off-load. When the last pallet is being loaded on the truck, the forklift informs the central system that the truck is loaded and ready to go. It can then leave the loading area and is replaced by the next truck. This warehouse system takes many parameters into account to determine constraints and optimal loading conditions: truck volume, forklift capacity, loading-bay location, and the number of forklifts in service. Automated systems not only allow fewer opportunities for errors, minimized inventory costs, and flexible supply chains, but also for denser storage capacities.

Hassia's Agile Supply Chain

Hassia has a network of three warehouses to manage deliveries of some 800 million liters every year. Orders are placed by Carrefour and are also delivered to both high-end restaurants and large retailers. Restaurants typically order smaller quantities and various products with mixed pallets. When bulk orders are placed from the retailer's warehouses, replenishment lead times are taken into account in the foreign destination location and by Hassia's warehouses. This helps prioritizing shipments during peak time and ensures the constant flow of the overall supply chain to avoid bottle-necks. Restaurants in Germany or Benelux can receive their order within 48 hours. In restaurants the water is served in glass bottles and these are retrieved when emptied. Hassia has to manage the reverse supply chain of these bottles. They will be collected when the next order is delivered. Once back at the bottling plant, they will be stripped from any labeling, thoroughly washed and reintegrated into the supply chain.

All these variations of the supply chain are possible thanks to the efficient management of the warehouse. Furthermore, with fewer intermediaries in the process the supply chain is made more agile. The ability to reach out-station customers makes this high-end European water product even more appealing.

QUESTIONS

1. Explain why the use of RFID increases supply chain efficiency.
2. Discuss the difficulty in supply chain management (SCM) to assemble mixed pallets in an efficient way.
3. Illustrate the need of modeling a warehouse facility and the inherent costs of empty runs.

Source: This case was prepared by Xavier Pierron, Coventry Business School, UK as a basis for classroom discussion. *Hassia Water International* (2011) Hassia Water International, www.hassiagroup.com/english/home/, accessed October 30, 2011.

Bret Hartman/AP Images

A FedEx plane is loaded with relief aid for the Philippines at the Los Angeles International Airport on Saturday, November 23, 2013. The supplies, needed by the victims of Typhoon Haiyan, consisted of shipments from Kansas City, KS and Santa Barbara, CA.

15

MANAGING SUPPLY CHAIN SUSTAINABILITY

FedEx

FedEx is a $44-billion-a-year delivery service company that is used to dealing with crises. Hardly a day goes by without disruptive events such as social unrest, major storms, or unanticipated labor strikes somewhere in the world. FedEx has designed a supply chain that is flexible and responsive to unpredictable catastrophic events. This capability, along with the logistical capacity of nearly 700 planes and 75,000 trucks, has made FedEx an important resource in disaster relief supply chains, which experience major mismatches of supply and demand that require a global response as quickly as possible. A wait-and-see attitude will not work; advanced planning is necessary. FedEx has 15 meteorologists and other staff members who monitor news and weather reports, which is a useful early-warning system in the event of emergencies. When disaster strikes, flight operation managers assign crew members to cargo planes destined for remote destinations. Sometimes they have to fight through red tape and obtain landing rights at locations where FedEx does not have operations.

FedEx, UPS, DHL, and other major logistics providers are quick to respond to disasters and take advantage of their vast logistic networks. FedEx sets aside space for as much as 4 million pounds of charitable shipping each year. Nonetheless, despite all of the readiness and preplanning, nobody could have predicted the devastation provided by Typhoon Haiyan on November 8, 2013, in the Philippines and surrounding area. In a span of 3 days, 6,300 people lost their lives, nearly 29,000 were injured, 4.1 million were displaced, 2.5 million were in need of food, and 1.2 million homes were destroyed. The storm was rated a Category 5 hurricane, with wind gusts as high as 225 miles per hour. The Philippine infrastructure, including airports, roads, and bridges, was devastated. In total, it is estimated that 16 million people were affected by the storm. How did FedEx respond to the need for humanitarian aid? FedEx worked with Heart to Heart International and Direct Relief, two philanthropic organizations dedicated to helping those impacted by disasters worldwide, to ship more than 200,000 pounds of pharmaceutical and medical supplies to the affected area. On November 18, 2013, FedEx picked up 125 pallets of medical aid from Heart to Heart International in Kansas City, Kansas, and shipped the cargo by truck to Los Angeles, California. On the same day, FedEx picked up another 125 pallets of supplies from Direct Relief in Santa Barbara, California, and shipped the cargo to Los Angeles, California. On November 23, 2013, at FedEx's distribution facility in Los Angeles, California, the shipments were loaded onto a MD-11 cargo plane for the more than 7,300-mile trip to the Philippines. On November 25, 2013, the cargo of medicines, hospital supplies, and personal care kits arrived in Cebu, Philippines, for distribution by local organizations. Participation in disaster relief efforts is one way organizations, such as FedEx, achieve social responsibility with their supply chains.

Source: "Quick Facts: What You Need to Know about Super Typhoon Haiyan," **http://www.mercycorps.org**; "Typhoon Haiyan," **http://en.wikipedia.org**; **http://www.fedex.com/us/about/responsibility/** (2014); Belson, Ken, "In Case of Disaster, Carriers Stand Ready to Airlift Aid," **NYTimes.com** (November 10, 2010).

LEARNING GOALS *After reading this chapter, you should be able to:*

1. Define the three elements of supply chain sustainability.
2. Explain the reverse logistics process and its implications for supply chain design.
3. Show how firms can improve the energy efficiency of their supply chains by using the nearest neighbor (NN) heuristic for logistics routes and determining the effects of freight density on freight rates.
4. Explain how supply chains can be organized and managed to support the response and recovery operations of disaster relief efforts.
5. Describe the ethical issues confronting supply chain managers.
6. Explain how a firm can manage its supply chains to ensure they are sustainable.

FedEx is an excellent example of how a firm designs its own supply chain to be reactive to major disruptions and natural disasters, a capability that also comes in handy when called upon to assist others in disaster relief causes. While effective supply chain design and integration is a capability that an organization can use to be more competitive in its industry, it can also be used to become a better corporate citizen. A growing theme among many corporations is that of responsible stewardship of the capital, ecological, and human resources that they and their suppliers use in the production of their services or products. Translated into a goal, these corporations strive to have services, products, and processes with the characteristic of **sustainability**, which means that they are meeting humanity's needs without harming future generations.[1] The topic of sustainability has many implications for a firm; however, in this chapter we focus only on supply chains and how they can be used to achieve sustainability.

sustainability

A characteristic of processes that are meeting humanity's needs without harming future generations.

Integrated supply chains can facilitate the implementation of sustainable operations because of their established communication and material flows. Nonetheless, achieving sustainability throughout the supply chain is no easy task. It requires cross-functional and inter-firm cooperation to address challenges such as:

- *Environmental protection*—firms should monitor their own processes and those of their suppliers to improve waste elimination methods, to reduce the pollution of the air, streams, and rivers, and to increase efforts at ecological stewardship for the protection of flora and fauna.

[1]For a more complete discussion of sustainability and what major corporations are doing, see Pete Engardio, "Beyond the Green Corporation," *Business Week* (January 29, 2007), pp. 50–64.

- *Productivity improvement*—firms should examine processes up and down the supply chain to increase material conservation, to increase energy efficiency, and to look for ways to convert waste into useful by-products.
- *Risk minimization*—as the supply chain grows, particularly on a global basis, firms should take great care to ensure that the materials that go into their services, products, or processes do not pose health or safety hazards to customers.
- *Innovation*—as new services, products, or technologies are designed and developed, firms should strive to make sure that they support their financial, environmental, and social responsibilities while serving the needs of customers.

▲ **FIGURE 15.1**
Supply Chains and Sustainability

A survey of 766 CEOs of major corporations conducted by the Accenture Institute for High Performance revealed that 93 percent of the CEOs believe that sustainability issues are critical to the future success of their companies, and 91 percent of them will employ new technologies (renewable energy, energy efficiency, information and communication) over the next five years.[2] Further, 88 percent of the CEOs believe that they should be integrating sustainability through their supply chains; however, only 54 percent believe that it has been achieved. Why is there a gap? While intuitively appealing, and the opinions of the CEOs notwithstanding, sustainability is not the easiest strategy for which approval can be gained from most boards of directors. Directors often need some sort of demonstrable return on investment to justify the costs. For sustainability efforts, however, managers must have a long-term view that accepts lower returns in the near future to improve the chances of survival and better returns in the future.

The Three Elements of Supply Chain Sustainability

As Figure 15.1 shows, supply chain sustainability has three elements. First, **financial responsibility** addresses the financial needs of the shareholders, employees, customers, business partners, financial institutions, and any other entity that supplies the capital for the production of services or products or relies on the firm for wages or reimbursements. Supply chains, for their part, support the financial responsibility of a firm by influencing elements that contribute to the return on assets as explained in Chapter 12, "Designing Effective Supply Chains." Furthermore, because supply chains are essentially linked processes, any improvement to processes or their management, as explained in Parts 1 and 2 of this text, improves the financial well-being of the firm and increases its chances of survival in a competitive world. Second, **environmental responsibility** addresses the ecological needs of the planet and the firm's stewardship of the natural resources used in the production of services and products. The goal is to leave as small an environmental footprint as possible so that future generations can make use of abundant natural resources. The design and integration of supply chains can play a major role in preserving resources. We shall examine how supply chains can be designed to produce products and then reprocess them at the end of their lives to yield value in the form of remanufactured products or recycled materials. We will also examine how supply routes can be planned to reduce the amount of energy consumed in delivering materials or products to customers.

Finally, **social responsibility** addresses the moral, ethical, and philanthropic expectations that society has of an organization. While this responsibility covers a broad range of activities, supply chains can be used to meet such expectations. Firms can engage in **humanitarian logistics**, which is the process of planning, implementing, and controlling the efficient, cost-effective flow and storage of goods and materials, as well as related information, from the point of origin to the point of consumption for the purpose of alleviating the suffering of vulnerable people. As such, firms can use their expertise in supply chain management to design supply chains that provide disaster relief, or to supply much needed drugs and food to undeveloped areas of the world. Ethical considerations also arise in the choice of suppliers regarding their practices in the use of labor and natural resources, the relationship between buyers and sellers, the location of facilities, and inventory management. Table 15.1 provides some examples of well-known firms addressing sustainability.

As we have already devoted most of the text to the financial implications of processes, supply chains, and their management, we now turn to the role of supply chains in achieving a firm's environmental and social responsibilities.

financial responsibility
An element of sustainability that addresses the financial needs of the shareholders, employees, customers, business partners, financial institutions, and any other entity that supplies the capital for the production of services or products or relies on the firm for wages or reimbursements.

environmental responsibility
An element of sustainability that addresses the ecological needs of the planet and the firm's stewardship of the natural resources used in the production of services and products.

social responsibility
An element of sustainability that addresses the moral, ethical, and philanthropic expectations that society has of an organization.

humanitarian logistics
The process of planning, implementing, and controlling the efficient, cost-effective flow and storage of goods and materials, as well as related information, from the point of origin to the point of consumption for the purpose of alleviating the suffering of vulnerable people.

[2] "A New Era of Sustainability: UN Global Compact—Accenture," Accenture Institute for High Performance. (June 2010), pp. 1–66.

TABLE 15.1 | **EXAMPLES OF SUPPLY CHAIN SUSTAINABILITY EFFORTS**

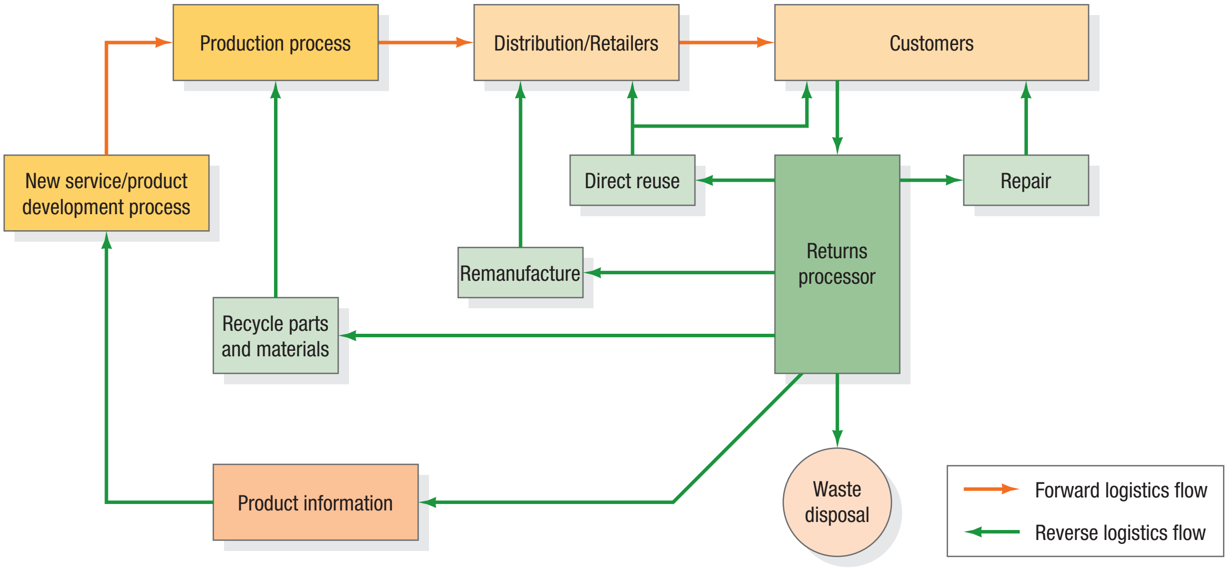
Financial Responsibility		Example
		NCR: In moving from a country-centric model to a global low-cost manufacturing model, where the majority of product is produced in Asia, import duties, tariffs, distances, fuel, and lack of capacity in the logistical carrier base must be considered along with the occasional need to create the logistics infrastructure to move the product. ***Nike:*** In analyzing the tradeoff in the costs of manufacturing products on-shore versus offshore, Nike has found that for plants in Europe it could pay 13 percent more in price for local sourcing and still be as well off as sourcing the production from offshore manufacturers.
Environmental Responsibility		
	Reverse Logistics	***Caterpillar:*** Its remanufacturing facilities recycle over 2 million pieces and 140 million pounds of materials annually in state-of-the-art factories worldwide. ***IBM:*** Its Global Asset Recovery division in one year collected over one million units of used information technology equipment that was converted to billions of dollars in revenues on the second-hand equipment, parts, and materials markets.
	Efficiency	***RR Donnelley:*** Proactively worked with suppliers to help find ways to use less packaging and to reuse or recycle what cannot be eliminated. ***UPS:*** Added 48 heavy-duty trucks, powered by liquefied natural gas (LPG), to cut diesel use by 95 percent while emitting 25 percent fewer greenhouse gasses.
Social Responsibility		
	Disaster Relief Supply Chains	***Intel and Solectron:*** In collaboration with the International Rescue Committee, these firms use their corporate expertise on disaster relief to significantly streamline procurement and create processes to substantially reduce response times. ***DHL:*** Uses its comprehensive logistic networks and worldwide presence to help people and communities affected by major sudden-onset natural disasters.
	Ethics	***Airbus:*** Places its highest priority on environmental performance, and supports green economy and technology transfers in developing countries. ***The Body Shop:*** Produces environmentally and ethically-focused cosmetics and requires all suppliers to sign on to its corporate code of conduct before trading with them.

reverse logistics

The process of planning, implementing, and controlling the efficient, cost-effective flow of products, materials, and information from the point of consumption back to the point of origin for returns, repair, remanufacture, or recycling.

Reverse Logistics

Environmental concerns regarding business are voiced every day in the popular media. Service providers are examining ways to increase efficiency and reduce the impact of their operations on the environment. Manufacturers are feeling pressure to take responsibility for their products from birth to death. To address environmental concerns and to manage their products throughout their life cycles, firms such as Coors Brewing Company, Dell, and Caterpillar are turning to **reverse logistics**, which is the process of planning, implementing, and controlling the efficient, cost effective flow of products, materials, and information from the point of consumption back to the point of origin for returns, repair, remanufacture, or recycling.



▲ **FIGURE 15.2**
Flows in a Closed-Loop Supply Chain

MyOMLab Animation

Supply Chain Design for Reverse Logistics

How are supply chains designed to be environmentally responsible for the entire life cycle of a product? A supply chain that integrates forward logistics with reverse logistics is called a **closed-loop supply chain** because it focuses on the complete chain of operations from the birth to the death of a product. Figure 15.2 shows how a product starts its journey at the new service/product development process, makes its way to the customer, and then enters the reverse logistics chain that attempts to maximize the value of the item at the end of its useful life.

closed-loop supply chain

A supply chain that integrates forward logistics with reverse logistics, thereby focusing on the complete chain of operations from the birth to the death of a product.

It is clear that the reverse logistics operations are considerably different from the forward logistics flows, and several times more expensive. A firm must establish convenient collection points to receive the used goods from the final customer and transport the goods to a *returns processor*, which is a facility owned by the manufacturer or outsourced to a supplier that is proficient at disassembling products and gleaning any remaining value from them. Several options exist. If the item is inoperable, it could be repaired and returned to the customer. Another option is that it could be cleaned and refurbished for direct use and returned either to the distribution channel, which is the case with leased products, or back to customers, which is the case with a maintenance warranty. The product could be remanufactured by tearing it down, rebuilding it with new parts as needed, and returning it to the distribution channel. Finally, the product could be completely disassembled and the usable parts and materials cleaned, tested, and returned to the production process. There are two important by-products of the reverse logistics process: waste, which must be properly disposed of, and product information, which is transmitted to the new service/product development process so that improvements can be made to future generations of the product.


Peter Essick/Aurora Photos/Corbis

Sorters separate electronic components at the Mueller-Guttenbrunn Metal recycling facility in Amstetten, Austria. This is where electronics goods as well as cars and other appliances are sent for recycling under the European Waste Electrical Electronics Equipment (WEEE) initiative. Trucks bring the electronics and small appliances into the facility where they are loaded into a smasher that breaks them up. Sorters sort out the circuit boards, capacitors, and other components while the remaining waste is shredded and sent out for metals recovery.

Reverse logistics processes can be particularly important in the electronics industry. Have you ever wondered what happens to your old computer after you purchase a new one? You may have given it to the store where you purchased your new one, or merely slipped it into the household trash. More retired computers in the United States are dumped in landfills than are recycled. Old computers contain electronics components with materials that can be recycled. However, they also have toxins that leach into the soil if these components are left unprocessed: lead and cadmium in computer circuit boards, lead oxide and barium in computer monitors and cathode-ray tubes (CRT), mercury in switches and flat screens, and fire retardant on printed circuit boards and plastic casings.

Many recycling processors are located in developing countries and are typically low tech. Recyclable material is collected and processed. Workers, who usually do not wear protective gear, often toss the chemicals that come out during the processing into nearby streams and rivers. Other materials not processed often are left in the dumps, allowing the toxins to leak out. This disregard for the

MANAGERIAL PRACTICE 15.1 Recycling at Walmart

All companies can save money by reducing the amount of waste they must dispose. Walmart, owing to its size, is certainly no exception. In the United States alone, Walmart has over 4,000 stores and serves 130 million shoppers a week. You can imagine the amount of trash that accumulates on a daily basis. Many trash items, such as loose plastic, plastic hangers, office paper, and aluminum cans, are unruly and difficult to collect for recycling. To attack this problem, Walmart initiated the "super sandwich bale (SSB)" at all of its stores and clubs in the United States. The SSB is an invention of Jeff Ashby, national accounts manager for Rocky Mountain Recycling in Salt Lake City. The associates place 10 to 20 inches of cardboard at the bottom of large trash compactors. Commodities, such as loose plastic bags, aluminum cans, plastic hangers, and plastic water and soda bottles, are loaded in, and another layer of cardboard is placed on top. The compactor then presses the bale into a "sandwich" with 9 to 18 inches of recyclables in the middle. The bales are then loaded onto a truck to be recycled into various raw materials that will ultimately become products once again. For example, in one of its sustainability programs, Walmart directs recycled plastics and cardboard to Worldwise, a leader in developing, manufacturing, and marketing sustainable pet products, where they are transformed into a stylish and durable line of dog beds. Plastic hangers are turned into litter pans, plastic bags into litter liners, and corrugated cardboard into cat scratchers. To get a sense of the value involved, Walmart used to pay trash companies to haul more than one billion plastic hangers from its stores and clubs each year. Now, it gets paid 15 to 20 cents a pound for them. The money adds up in a hurry. Who said that reverse logistics supply chains are not profitable? It is clear that environmentally conscious supply chain operations can literally turn "trash" into "cash."

Tom Uhlman/AP Photo

A Walmart employee throws used packaging boxes into a compactor as a first step in building a super sandwich bale at a Cincinnati area Walmart. The giant retailer is urging its suppliers to reduce greenhouse gas emissions on top of its own moves to build more energy-efficient stores, use alternative fuels for its truck fleet, and reduce packaging.

Source: Marc Gunther. "The End of Garbage," *FORTUNE*, (March 19, 2007), pp. 158–166; "Waste," **http://www.walmartstores.com**, (2014); Elaine Jarvik, "Super sandwich bale—Utah Man's Idea Nets Wholesale Recycling," Desert News, (April 22, 2008); "Walmart Rolls Out the Plastic Sandwich Bale," **http://www.walmartstores.com**, 2005; "Walmart Annual report 2013, **http://www.walmart.com**.

environment prompted a backlash against the improper disposal of electronic equipment in developed countries. The European Union (EU) passed a law requiring electronics manufacturers to take back and recycle 75 percent of the products they sell in the EU. Some states in the United States banned *e-waste*, electronic components and the chemical by-products of the recycling process, from landfills and are considering making electronics manufacturers responsible for managing e-waste.

Recycling is a major aspect of reverse logistics. Managerial Practice 15.1 provides an example of how a major retailer uses recycling to be environmentally responsible.

Financial Implications

Some firms participate in reverse supply chains by owning and operating processes such as remanufacturing, recycling, or repairing the used products and materials. These firms benefit from reclaiming usable parts for their manufacturing operations or by selling remanufactured products at competitive prices. If an original equipment manufacturer (OEM) participates in remanufacturing, however, there is a fear that the remanufactured products will cannibalize the sales of the firm's new products. Often these fears give rise to restrictions such as floors on the price that can be charged for remanufactured products, limits on the markets where they can be sold, limits on the distribution channels the products can be sold through, and reduced warranties that can be offered on them. Of course, there are also opportunity costs for not remanufacturing. There is the danger that environmentally irresponsible product disposal practices on the part of the firm's customers may result in the firm facing costly regulatory restrictions in the future. Also, third-party manufacturers may participate in the reverse logistics supply chain by collecting or purchasing the unclaimed old products, remanufacturing them, and then selling them in competition with the firm's new products. That is the case with refilled laser printer and inkjet cartridges, which erodes profit margins for original printer manufacturers like Hewlett-Packard, Dell, and Epson.

Other firms, as well as individuals, participate in the reverse logistics supply chain by supplying their used products and materials for processing. A continuous supply of these unused products and materials is needed to make the reverse supply chain financially viable. Various incentives may be used to influence the quantity, the quality (condition), and the timing of supply. Examples of incentives include:

- *Fee.* A fee is paid to the user when a used product or recyclable material is delivered for recovery. Usually the fee depends on the condition of the product or material because this may determine the possibilities for its reuse. Of course, we have seen how some firms such as Walmart can garner substantial revenues from the recycling of useful materials they previously discarded.
- *Deposit fee.* Such fees provide incentive for the user to return the product or containers of the product to get the reimbursement of the deposit fee. This fee may relate to the product itself, such as a rental trailer, which must be refurbished (cleaned, maintained) before allowing the next customer to use it. Alternatively, the fee may apply to the distribution of the product, such as the deposit fee on beer bottles in some states.
- *Take back.* A company may offer to collect its products from its customers for no charge when those customers want to dispose of them. Dell, for example, charges no fees to recycle old computers from customers. Dell has designed its computers to make them easier to disassemble and recycle.
- *Trade-in.* One can get a new copy of a product if another copy is returned. For example, purchasing a refurbished engine for an automobile often requires the owner to turn in the old one, which might be disassembled for its parts or refurbished for sale to another customer.
- *Community programs.* Often communities or groups will set aside special days for the disposal of various items that are difficult to dispose of, such as automobile tires, paint, metal, and other things that the trash collectors do not normally pick up.

Many firms and individuals submit their used products and materials to be recycled for no other reason than it is the environmentally correct thing to do. Nonetheless, without the incentives, many reverse logistics supply chains would dry up.

Energy Efficiency

Supply chains involve the flow of materials and services from their origination to their ultimate destination. As such, supply chains consume energy. Energy consumption not only is expensive from a business perspective, but it can also have negative effects on the environment. Increasingly more firms are measuring their **carbon footprint**, which is the total amount of greenhouse gasses produced to support their operations, usually expressed in equivalent tons of carbon dioxide (CO_2). Major contributors to carbon footprints are fossil fuels, in particular oil, diesel, and gasoline, which are used extensively in supply chain logistical operations. Therefore, it behooves firms to be efficient with respect to energy consumption throughout their supply chain. In this section, we will discuss three levers supply chain managers can use to increase the energy efficiency of their operations: (1) transportation distance, (2) freight density, and (3) transportation mode.

carbon footprint

The total amount of greenhouse gasses produced to support operations, usually expressed in equivalent tons of carbon dioxide (CO_2).

Transportation Distance

Supply chain managers can decrease the amount of energy consumed in moving materials or supplying services by reducing the distance traveled. There are two ways this can be accomplished. The first involves the design of the supply chain itself. Locating service facilities or manufacturing plants in close proximity to customer populations reduces the distance required to supply the service or product. Furthermore, selecting suppliers that are in close proximity to the service facilities or manufacturing plants reduces the amount of fuel needed to procure those materials. Of course, these suppliers must meet the firm's quality and performance needs. See Chapter 13, "Supply Chains and Logistics" and Chapter 14, "Integrating the Supply Chain," for details.

A second way to improve energy efficiency involving transportation distances is **route planning**, which seeks to find the shortest route to deliver a service or product. Once the design of the supply chain has been determined, attention turns to minimizing the distance traveled to supply the service or product to customers on a daily basis. There are two traditional versions of this problem. The first is the **shortest route problem**, which seeks to find the shortest distance between two cities in a network or map. While elegant mathematical methods have been developed for solving this problem, today we are fortunate to have GPS systems for vehicles and Web sites such as Mapquest™ where very good, energy efficient, routes can be obtained quickly. Manufacturers with their own delivery fleets or third-party logistics providers (3PLs) can use these routes to minimize their costs of making the deliveries.

route planning

An activity that seeks to find the shortest route to deliver a service or product.

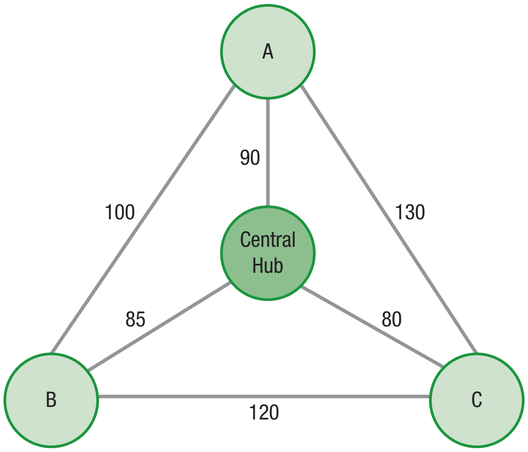
shortest route problem

A problem whose objective is to find the shortest distance between two cities in a network or map.

The second version is known as the **traveling salesman problem**, which seeks to find the shortest possible route that visits each location or city exactly once and returns to the starting location. This problem is a much more difficult one to solve, yet one which delivery services face every day. Starting from a central location, such as a warehouse, distribution center, or hub, orders headed for multiple destinations are loaded into a truck that must make the deliveries, or alternately pick up supplies, and return to the

traveling salesman problem

A problem whose objective is to find the shortest possible route that visits each city exactly once and returns to the starting city.



▲ **FIGURE 15.3**
Four-City Traveling Salesman Problem

central location. The problem is to find the sequence of cities the truck must visit so that the total miles traveled is minimized. Figure 15.3 shows a four-city traveling salesman problem with the driving miles between each city shown on the arc connecting them. How many different routes are there in Figure 15.3? Because we are dealing with driving distances between the cities, and there are no anomalies such as one-way streets or road blockages, the route Central Hub–A–C–B–Central Hub, for example, has the same total distance as the reverse of that route, Central Hub–B–C–A–Central Hub. Consequently, there are only three different routes:

Central Hub–A–B–C–Central Hub, which is $90 + 100 + 120 + 80 = 390$ miles.

Central Hub–B–C–A–Central Hub, which is $85 + 120 + 130 + 90 = 425$ miles.

Central Hub–C–A–B–Central Hub, which is $80 + 130 + 100 + 85 = 395$ miles.

The optimal route for the example is Central Hub–A–B–C–Central Hub.

It may look easy to find the best route; simply evaluate each possible route as we just did. However, if the truck must visit n cities there are $(n - 1)!/2$ different routes to consider. For example, if there are only eight cities to visit, there are 2,520 possible routes to consider.[3] While complete enumeration of all the feasible routes is one way to solve this problem, the computational effort becomes onerous. If you were faced with the problem in Figure 15.3, how might you proceed to solve it in the absence of a brute force approach? You might do the following: Start with the Central Hub and go to the closest unvisited city; from that city find the next closest unvisited city, and repeat until you get back to the Central Hub. This approach is called the **nearest neighbor (NN) heuristic**, and has the following steps:

nearest neighbor (NN) heuristic
A technique that creates a route by deciding the next city to visit on the basis of its proximity.

1. Start with the city that is designated as the central location. Call this city the *start* city. Place all other cities in an *unvisited* set.
2. Choose the city in the unvisited set that is closest to the start city. Remove that city from the unvisited set.
3. Repeat the procedure with the latest visited city as the start city.
4. Conclude when all the cities have been visited, and return back to the central location.
5. Compute the total distance traveled along the selected route.

Using the NN heuristic for the problem in Figure 15.3 yields the following route: Central Hub–C–B–A–Central Hub, for a total distance of 390 miles. Notice that this is the optimal solution to the problem. The NN heuristic does not always yield the optimal solution; however its main advantages are that it is fast and that it generally provides reasonable solutions to a very complex problem. Example 15.1 shows the application of the NN heuristic for the delivery of natural food products.

EXAMPLE 15.1 Finding an Energy-Efficient Route Using the Nearest Neighbor Heuristic

Hillary and Adams, Inc., is a privately owned firm located in Atlanta that serves as the regional distributor of natural food products for Georgia, Kentucky, North Carolina, South Carolina, and Tennessee. They are particularly well known for their unique blend of fiery hot Habanera sauces. Every week, a truck leaves the large distribution center in Atlanta to stock local warehouses located in Charlotte, North Carolina; Charleston, South Carolina; Columbia, South Carolina; Knoxville, Tennessee; Lexington, Kentucky; and Raleigh, North Carolina. The truck visits each local warehouse only once and returns to Atlanta after all the deliveries have been completed. The distance between any two cities in miles is given below.

From/To	Atlanta	Charleston	Charlotte	Columbia	Knoxville	Lexington	Raleigh
Atlanta	–	319	244	225	214	375	435
Charleston	319	–	209	116	373	540	279
Charlotte	244	209	–	93	231	398	169
Columbia	225	116	93	–	264	430	225
Knoxville	214	373	231	264	–	170	351
Lexington	375	540	398	430	170	–	498
Raleigh	435	279	169	225	351	498	–

[3]We assume that there are roads connecting each pair of cities. The factorial is divided by two because the sequence of cities visited in one tour is assumed to have the same distance as a tour with the cities in reverse sequence.

John Jensen, vice president of logistics at Hillary and Adams, Inc., is worried about the rising fuel costs. With a reduction in operating budgets, he is interested in finding a route that would minimize the distance traveled by the truck.

Use the NN heuristic to identify a route for the truck and compute the total distance traveled.

SOLUTION

The application of the NN heuristic results in the following steps:

1. Start with Atlanta and place all other cities in the unvisited set: Charleston, Charlotte, Columbia, Knoxville, Lexington, Raleigh.
2. Select the closest city to Atlanta in the unvisited set, which is Knoxville. Remove Knoxville from the unvisited set. The partial route is now Atlanta–Knoxville, which is 214 miles.
3. Scan the unvisited set for the city closest to Knoxville, which is Lexington. Remove Lexington from the unvisited set. The partial route is now Atlanta – Knoxville – Lexington, which is $214 + 170 = 384$ miles.
4. Repeat the procedure until all cities have been removed from the unvisited city set. Connect the last city to Atlanta to complete the route.
5. Compute the total distance traveled along the selected route. The route using the NN heuristic is Atlanta–Knoxville–Lexington–Charlotte–Columbia–Charleston–Raleigh–Atlanta. The total distance traveled is $(214 + 170 + 398 + 93 + 116 + 279 + 435) = 1705$ miles.

Note that using the same sequence of cities we could start the route at any one of them and travel the same total distance. For example, the route Lexington–Charlotte–Columbia–Charleston–Raleigh–Atlanta–Knoxville–Lexington will also be 1705 miles. This fact allows us to use the NN heuristic again to see if a better solution exists; we repeat the heuristic six more times using each city as the starting point. This approach results in the following routes:

- Charleston–Columbia–Charlotte–Raleigh–Knoxville–Lexington–Atlanta–Charleston $(116 + 93 + 169 + 351 + 170 + 375 + 319) = 1{,}593$ miles.
- Charlotte–Columbia–Charleston–Raleigh–Knoxville–Lexington–Atlanta–Charlotte $(93 + 116 + 279 + 351 + 170 + 375 + 244) = 1{,}628$ miles.
- Columbia–Charlotte–Raleigh–Charleston–Atlanta–Knoxville–Lexington–Columbia $(93 + 169 + 279 + 319 + 214 + 170 + 430) = 1{,}674$ miles.
- Knoxville–Lexington–Atlanta–Columbia–Charlotte–Raleigh–Charleston–Knoxville $(170 + 375 + 225 + 93 + 169 + 279 + 373) = 1{,}684$ miles.
- Lexington–Knoxville–Atlanta–Columbia–Charlotte–Raleigh–Charleston–Lexington $(170 + 214 + 225 + 93 + 169 + 279 + 540) = 1{,}690$ miles.
- Raleigh–Charlotte–Columbia–Charleston–Atlanta–Knoxville–Lexington–Raleigh $(169 + 93 + 116 + 319 + 214 + 170 + 498) = 1{,}579$ miles.

Of the seven routes produced with the NN heuristic, the best is the last one with a travel distance of 1,579 miles.

DECISION POINT

Minimizing the number of miles to complete a route reduces the amount of fuel consumed by Hilary and Adams for the delivery process. Since each route is a loop, the truck driver would be instructed to go from Atlanta to Knoxville to Lexington to Raleigh to Charlotte to Columbia to Charleston and back to Atlanta. Alternatively, the reverse sequence could be taken; go to Charleston first, and so on. The sequence of cities dictates how the truck is loaded. The travel distances would still be 1,579 miles. While the NN heuristic cannot guarantee an optimal solution, it can help John Jensen avoid a costly mistake. For example, the route Atlanta–Raleigh–Lexington–Charleston–Knoxville–Columbia–Charlotte–Atlanta is 2,447 miles, a 55 percent increase in mileage over the best NN solution. Consequently, in addition to being environmentally responsible, the NN solution supports the competitive priority of low-cost operations. Minimizing the distance traveled to complete the route also shortens the time required to make the deliveries, which supports the competitive priority of delivery speed.

Freight Density

Truck vans, containers, and rail cars all have limits with respect to cargo volume and weight. By reducing the volume that a product displaces while staying within the weight limits of the conveyance, the firm can use fewer trucks, containers, or rail cars to ship the same number of units. Freight density, measured in pounds per cubic foot, determines the freight class and the cost a shipper must pay. The lower the freight density, the higher the freight class because the volume of the conveyance will be maxed out

James Hardy/PhotoAlto/Alamy

The shipper of these wrapped pallets of cardboard boxes will be charged a freight rate based on six factors, including density, weight, and distance.

before the weight limit is reached. For example, 1,000 pounds of ping pong balls occupy much more room in a trailer than 1,000 pounds of bowling balls. Firms can increase the freight density by reducing the volume of packaging, redesigning the product to take less volume, or postponing the assembly of the product until the customer takes possession.

Firms using 3PLs to get their materials or products to their customers must pay a freight rate based on six factors:

1. The freight density
2. The shipment's weight
3. The distance the shipment is moving
4. The commodity's susceptibility to damage
5. The value of the commodity
6. The commodity's loadability and handling characteristics (loadability refers to how efficiently the items being shipped fit into a standard container or truck van. Also, in some cases special care must be taken in handling during the loading and unloading processes.)

Table 15.2 shows example freight rates and weight breaks based on various freight classifications for a shipment scheduled between two specific zip codes. The rates are given in dollars per hundredweight (cwt). The freight classification for a shipment is determined by the National Motor Freight Classification (NMFC) tariff and is based upon the last four factors in the list above. There are 18 possible freight classes ranging from 50 to 500. The tariffs in the table are based on the distance to be traveled and are modified by the weight and freight class. Notice how the rates increase as the class goes up and decrease as the weight goes up.

Using Table 15.2, a shipment weighing 2,000 pounds and freight class 85 would cost $20(34.87) = \$690.74$. A 5,000-pound shipment of the same commodity would cost $50(26.60) = \$1{,}330$, which is more costly than the 2,000-pound shipment as we would expect. What rate will be charged if the shipper has a 4,000-pound shipment? Because the shipping weight falls between two weight breaks, we must see which of the two rates applies. Using the 2,000-pound rate the total charge would be $40(34.87) = \$1{,}394.80$. At the 5,000 pound rate, the total charge is $40(26.60) = \$1{,}064.00$. In this case, the shipper would only be charged \$1,064.00 even though the actual shipment does not meet the minimum for that rate. To determine the break-even weight between two adjacent weight breaks, we define the following variables:

x = break-even weight
A = lower weight bracket
B = next highest weight bracket
C = freight rate relative to A
D = freight rate relative to B

TABLE 15.2 | **EXAMPLE MATRIX OF WEIGHT BREAKS AND FREIGHT CLASS ($/CWT)**

Class	< 500 (lbs)	500 (lbs)	1,000 (lbs)	2,000 (lbs)	5,000 (lbs)	10,000 (lbs)	≥ 20,000 (lbs)
50	34.30	28.32	24.25	23.04	17.58	15.74	10.47
55	36.94	30.50	26.12	24.82	18.93	17.41	11.58
60	39.59	32.69	27.99	26.60	20.29	19.08	12.69
65	41.94	34.64	29.66	28.18	21.49	20.27	13.48
70	44.64	36.86	31.56	29.99	22.88	21.94	14.59
77.5	48.10	39.72	34.01	32.32	24.65	23.85	15.86
85	51.90	42.86	36.70	34.87	26.60	26.24	17.45
92.5	55.89	46.15	39.52	37.56	28.64	28.38	18.87
100	60.27	49.77	42.61	40.50	30.89	30.77	20.46

The break-even weight is given by

$$x = (BD)/C$$

In our example, the break-even weight is $(50)(26.60)/(34.87) = 38.14$, or 3,814 pounds. Any shipment greater than 3,814 pounds would enjoy the lower freight rate. Example 15.2 shows how a firm can find out if increasing freight density is in its best interests.

EXAMPLE 15.2 Evaluating an Increase in Freight Density

One of the products produced by Kitchen Tidy is Squeaky Kleen, a tile cleaner used by restaurants and hospitals. Squeaky Kleen comes in 5-gallon containers, each weighing 48 pounds. Currently, Kitchen Tidy ships four pallets of 25 units each week to a distribution center. The freight classification for this commodity is 100. Table 15.2 has the freight rates governing this shipment.

In an effort to be more environmentally responsible, Kitchen Tidy asked their product engineers to evaluate a plan to convert Squeaky Kleen into a concentrated liquid by removing some water from the product. The product would be essentially the same; however, the customer would have to add water to the concentrate before using it. This would allow engineers to design a smaller container so that 50 units can be loaded on each pallet. Each container of Squeaky Kleen would weigh only 42 pounds. The product redesign would increase the product's freight density and therefore reduce the freight class, which now would be 92.5.

Use Table 15.2 to determine the savings in freight costs Kitchen Tidy might expect from the new product design.

SOLUTION

Current product design

- The weekly shipment in pounds is (number of pallets)(units per pallet)(pounds per unit) $= (4)(25)(48) = 4{,}800$ pounds.
- The freight class is 100. The shipping weight falls between two weight break brackets. The break-even weight between these two weight breaks is $(50)(30.89)/(40.50) = 38.14$, or 3,814 pounds. Therefore, the shipment qualifies for the lower freight rate.
- The total weekly shipping cost is $48(30.89) = \$1{,}482.72$.

New product design

- The weekly shipment in pounds is (number of pallets)(units per pallet)(pounds per unit) $= (2)(50)(42) = 4{,}200$ pounds.
- The freight class is 92.5. The shipping weight falls between two weight break brackets. The break-even weight between these two weight breaks is $(50)(28.64)/(37.56) = 38.126$, or 3,813 pounds. The shipment of 4,200 pounds will get the lower rate.
- The total weekly shipping cost is $42(28.64) = \$1{,}202.88$.

The new product design will save Kitchen Tidy $\$1{,}482.72 - \$1{,}202.88 = \$279.84$ each week.

DECISION POINT

There are other potential benefits to the decision to move forward on the new product design. The smaller container for the product means less expensive packaging, which increases the profit margin of Kitchen Tidy. A smaller cubic volume also implies less warehouse space that must be devoted to this product. The environmental impact of this effort could be used to raise the image of Kitchen Tidy in the industry. Of course, care must be taken to educate the customers of Squeaky Kleen about the new product design so that they do not think they are getting less value for their money due to the smaller containers.

Transportation Mode

The four major modes of transportation are (1) air freight, (2) trucking, (3) shipping by water, and (4) rail. From an energy perspective, air freight and trucking are much less efficient than shipping or rail. According to the Association of American Railroads, on average, railroads are three times more fuel efficient than trucks, capable of moving a ton of freight 436 miles per gallon of fuel. The EPA also considers railroads best when it comes to noxious emissions per ton-mile. Further, freight railroads help relieve congestion on the highways; a typical train takes the freight equivalent of several hundred trucks. Trucks,

Trains and Planes/Alamy

Truck trailers, often referred to as "piggy back" trailers, catch a ride on a BNSF intermodal freight train near Wellington, KS for a cross-country journey.

nonetheless, are more flexible and can make deliveries right to the customer's door. Shippers can have the door-to-door convenience of trucks with the long-haul economy of railroads or ocean containers by employing **intermodal shipments**, which involves mixing the modes of transportation for a given shipment, such as moving shipping containers or truck trailers on rail cars. A huge range of consumer goods, from bicycles and lawn mowers to greeting cards and clothing, and an increasing amount of industrial and agricultural products, are being transported by intermodal shipments. All of these factors should be considered when designing an environmentally responsible supply chain.

There are other considerations, however, that enter the mode selection. Air freight is the fastest, but costly. Trucks, being the most flexible, can reach destinations where air freight, shipping by water along rivers or oceans, or rail is not economical or feasible. Shipping by water, a preferred mode for intercontinental shipments, typically can handle containers of greater weight, thereby minimizing the number of necessary shipments. In addition, each of the transportation modes offers opportunities for energy efficiency through their designs. Design factors include:

intermodal shipments

Mixing the modes of transportation for a given shipment, such as moving shipping containers or truck trailers on rail cars.

- Relative drag—the energy needed for propulsion of a vehicle of a given size at a given speed
- Payload ratio—the cargo-carrying capacity of the vehicle relative to the vehicle's weight when fully loaded
- Propulsion systems—the technology used to move the vehicle

Walmart, for example, purchased diesel-electric and refrigerated trucks with a power unit that could keep cargo cold without the engine running, saving nearly $75 million in fuel costs and eliminating an estimated 400,000 tons of CO_2 pollution in one year alone. Manufacturers and transportation services companies such as FedEx, UPS, and DHL actively replace old equipment with newer, energy-efficient equipment and greatly reduce their carbon footprints. In New Delhi, India, all commercial vehicles were mandated to use liquefied natural gas (LNG) to reduce the air pollution levels in the capital city. Designing a supply chain that addresses environmental concerns, while meeting a firm's competitive priorities, can be a challenging task.

Justin Kase zsixz /Alamy

UPS hybrid electric vehicle on the job making deliveries. Hybrid technology is one way major logistics suppliers such as UPS can increase their energy efficiency and reduce pollutants.

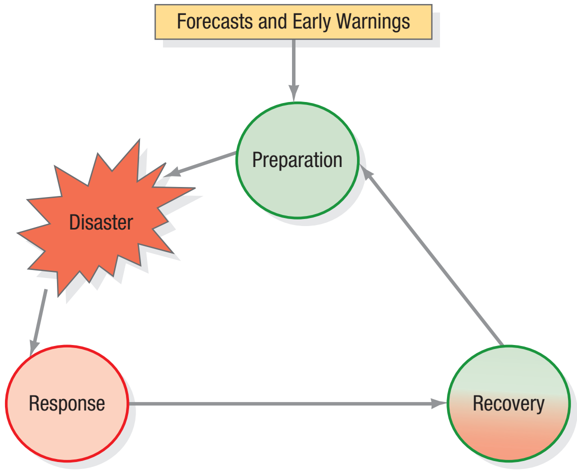
Disaster Relief Supply Chains

Beyond the financial and environmental responsibilities, firms and organizations are also recognizing that there are social responsibilities that must be recognized if they are to be considered good corporate citizens. Supply chain managers are in a unique position to be catalysts for social responsibility activities because they are boundary spanners: They interact internally with other key functional areas of the organization as well as externally with suppliers and customers. Nonetheless, supply chain managers cannot do it alone. Social responsibility should be the focus of the entire organization, including the top management.

Organizing for Disaster Relief

According to the United Nations, a *disaster* is a serious disruption of the functioning of society, causing widespread human, material, or environmental losses which exceed the ability of the affected people to cope using only its own resources. Disasters can be human-related (epidemic, war, genocide, insurgency, arson, or terrorism) or natural (earthquake, tsunami, hurricane, tornado, flood, or volcanic activity). Some disasters allow more planning time than others; all disasters put pressure on relief operations. Recent disasters such as the earthquakes in Haiti and Chile in 2010, the earthquake and tsunami in Japan in 2011, and typhoon Haiyan in the Philippines in 2013, are cases in point. Between 400 and 500 natural disasters strike per year affecting more than 250 million people, and 80 percent of all relief operations for all types of disasters require supply chains of some sort. Needless to say, supply chain managers play a vital role.

Disaster relief operations for major disasters often involve many organizations, typically led by the United Nations. Agencies such as the International Federation of Red Cross and Red Crescent Societies and many other philanthropic and faith-based organizations assist in the relief efforts under the leadership of the United Nations through programs such as the World Food Program or the UN Development Program. In addition, private third-party logistics providers, such as Agility, TNT, and UPS, have partnered with the UN to provide additional transportation capacity in the event of large-scale international disasters and to provide warehousing services in Italy, United Arab Emirates, Panama, and Ghana. The warehouses, referred to as strategic hubs, stockpile vital supplies in anticipation of major disasters in that area of the world. In a similar vein, FedEx has partnered with Heart to Heart International, a global humanitarian organization that works to improve health and to respond to the needs of disaster victims worldwide. Together, they have established four Forward Response Centers located in Kansas City, and internationally in Mexico, the Philippines, and the United Arab Emirates. Each center is stocked with 60–80 pallets containing basic relief supplies, which are ready to be moved to the affected area on a moment's notice. As these examples show, private corporations can be socially responsible by transferring, acquiring, and sharing their expertise and access to needed resources through formalized collaborations such as these.



▲ **FIGURE 15.4**
Humanitarian Supply Chain Operations

Figure 15.4 shows the three major humanitarian supply chain operations relating to disaster relief—preparation, response, and recovery—and the temporal relationship between them.

- *Preparation.* Forecasts and early warning systems can sometimes provide enough lead time to assemble the resources and organize the relief efforts. Often, however, disasters happen with little or no warning. Nonetheless, relief agencies can do some advance planning to reduce the response time. Communication protocols and the information technology infrastructure can be prepared. Strategic partnerships with other agencies and private companies can be formalized and training of agency personnel can be undertaken before the next disaster. Kits of standardized, nonperishable items can be preassembled and stocked, and some items can be placed in strategic hubs to reduce the delivery time when the need arises.
- *Response.* After the disaster strikes, the resources are mobilized and sent to the disaster location as soon as possible. The initial procurement of food, water, materials, and medicines are made, and personnel to provide assistance and humanitarian aid are dispatched to the region. A preliminary needs assessment is made by small multidisciplinary teams of experienced humanitarian workers and logisticians. Communication lines often are lacking. Coordination between international suppliers of needed items and the local authorities is often difficult because ports of entry are inaccessible, or the authorities are overtaken by events and inexperienced in events of this magnitude, or lacking in resources.
- *Recovery.* As time progresses, the crisis mode of "response" gives way to a focus on rebuilding the information and logistical infrastructure and rehabilitating the affected population. Supplies, food, and medicines can be ordered with more normal lead times as quantities can be better estimated. More focus is placed on the cost of these items. Collaboration and cooperation improves; however, supplies from all over the world sent during the response phase, often without consultation with teams on location, cause oversupply of some commodities.

Managing Disaster Relief Operations

Regarding the structure of supply chains and disaster relief operations, a firm's main supply chain processes of supplier relationship process, order fulfillment process, and customer relationship process remain essentially intact. The difference when it comes to disaster relief is that the timetable and ultimate customer for a supplier changes rapidly. Nonetheless, supply chain managers can provide the glue between the disaster relief operations. From the perspective of the disaster relief agencies, which oversee the relief operations relative to their organizations, supply chains must be designed to link the preparation activities to the initial response activities and ultimately the recovery operations. The procurement of materials, food, and medicines must be matched with their distribution to the affected areas, often

U.S. Marines Photo/Alamy

Philippine workers unload food and supplies to aid victims of Typhoon Haiyan on November 16, 2013 at Tacloban Air Base, Philippines. Many disaster relief supply chains contributed to the humanitarian effort.

involving trade-offs in delivery speed, cost, and consistent quality with regard to the type of goods and their quantities. Supply chain managers can do this; they can also link disaster relief headquarters with the operations in the field, whether those operations are response or recovery operations. For this reason, disaster relief organizations need supply chain managers on their staffs, something that few of them have.

In disaster relief operations, suppliers must understand that the morphology of supply chains changes over time. The life cycle of disaster relief supply chains has five stages: (1) brief needs assessment; (2) development of the initial supply chains for flexibility; (3) speedy distribution of the supplies to the affected region based on forecasted needs; (4) increased structuring of the supply chain as time progresses, whereby supplies arrive by a fixed schedule or on request; and (5) dismantling or turning over of the supply chain to local agencies. Suppliers, and their suppliers, need to be on the same page as this life cycle plays out; the timeframe and requirements can be different for each disaster. Supply chain managers who understand the implications of the disaster relief life cycle can mitigate its effects on their firm's operations while doing their best to support the relief agency's goals.

As listed below, the unpredictability and severity of disasters pose unique challenges to supply chain managers.

- *Design implications.* Many disaster relief supply chains exist for only short times. At the onset of a disaster, the supply chain could require a new design from scratch featuring quick response capabilities involving innovative suppliers. Response operations are all about speed and agility in the supply of needed items. Risk-taking is encouraged because the priority is quick access. Recovery operations, however, require a more scheduled program, favoring an efficient supply chain design.
- *Command and control.* In major international disasters, the United Nations typically has the leadership role. Disaster relief agencies work to supply the items and services they have access to. However, the national and local government of the affected region must be recognized and included. Sometimes the national government will not grant access to the area until it can ensure its security, or it will not allow access to relief agencies from some countries because of political reasons. In other words, critical supplies may not be deployed as soon as they are available because of national or local roadblocks.
- *Cargo security.* Shipping containers of goods in some Third World countries may experience theft or extra delays. Delays can be due to numerous police checks or weight checks. Sometimes, bribes are needed to move the cargo through the check points, all of which cause delays when speed is of the essence.
- *Donor independence.* There are many disaster relief agencies, all of which have the best of intentions to help relieve pain and suffering at the point of the disaster. If they are not coordinated with a list of required supplies, each sends what they think is needed. The result can be confusion, congestion, over stocking of some items, and under stocking of other items.
- *Change in work flow.* During the response operations, supplies are sent without waiting for demand to be accurately determined. Supplies are provided according to forecasts, however imperfect, using a *push flow* from suppliers. Once relief efforts reach the recovery operations, actual needs should dictate the required volume of supplies and the supply chains should switch to a *pull flow*.
- *Local infrastructure.* Because disasters often cause major damage to the infrastructure, roads, ports, railways, and airports may be compromised, thereby limiting the logistical movement of needed supplies. Local transportation capability may be limited. Often novel approaches must be used, such as helicopters moving supplies from ships at sea.
- *High employee turnover.* The needs of the disaster relief and the availability of qualified local labor are highly unpredictable. The manual processes often needed in disasters are poorly defined. Coupled with the uncertainty of funding from the relief agency, employee turnover tends to be high in disaster relief operations.
- *Poor communication.* Information technology is fragmented: telephone lines are disrupted, cell service is limited, and Internet access is unreliable.

Consequently, each disaster requires a unique supply chain solution. The flexibility to change and adapt to evolving conditions is a key attribute of disaster relief supply chains.

Supply Chain Ethics

Supply chains, by virtue of their interconnectedness with other firms and their intense internal and external human interactions, often pose ethical issues for their managers. In this section, we will explore some of the ethical issues associated with buyer–supplier relationships, location of facilities, and inventory management.

Buyer–Supplier Relationships

When an ethical issue arises, customers often blame the firm that sold them the service or product when in fact a supplier farther upstream was at fault. Selecting suppliers that adhere to ethical codes of conduct is a critical aspect of designing a supply chain. This is a difficult task; however, socially responsible firms have some guidance for selecting ethical suppliers. Social Accountability International, an organization dedicated to defining and verifying the implementation of ethical workplaces, has compiled **SA8000:2014**, which is a list of standards covering nine dimensions of ethical workforce management:

SA8000:2014
A list of standards covering nine dimensions of ethical workforce management.

1. *Child Labor:* Employ no underage workers, usually taken to be under 15 years of age.
2. *Forced or Compulsory Labor:* Prohibit the use of forced or compulsory labor, including prison or debt bondage labor.
3. *Health and Safety:* Provide a safe and healthy work environment.
4. *Freedom of Association and Right to Collective Bargaining:* Respect the right to form and join trade unions and bargain collectively.
5. *Discrimination:* Do not engage in or support discrimination based on race, caste, origin, religion, disability, gender, sexual orientation, union or political affiliation, or age; no sexual harassment.
6. *Disciplinary Practices:* Use no corporal punishment, mental or physical coercion, or verbal abuse.
7. *Working Hours:* Require no more than 48 hours per week with at least 1 day off for every 7-day period with overtime hours and pay subject to the collective bargaining agreement.
8. *Remuneration:* Pay wages for a standard work week such that they meet the legal and industry standards and be sufficient to meet the basic need of workers and their families.
9. *Management Systems:* There are 10 elements to this dimension that require actions on the part of management to meet and comply with the SA8000:2014 standards. Facilities seeking to gain and maintain certification must go beyond simple compliance to integrate the standard into their management systems and practices.

Once certified, firms need to be recertified every three years. As of June 2013, there were 3,231 certified facilities involving 1,862,936 workers in 72 countries and 65 industries. Standards such as SA8000:2014 go a long way toward building a supply chain that is socially responsible.

Beyond identifying suppliers with ethical workforce practices, firms should strive to select suppliers impartially, guided strictly by market criteria and competitive priorities. Preferential treatment of suppliers because of friendships, family ties, or investment in the supplier should be avoided. Buyers should be candid when negotiating contracts and have respect for the supplier's cost structure and any special efforts for performance improvements. Gratuities to the buyer should be limited or excluded. Other unethical activities include:

- Revealing confidential bids and allowing certain suppliers to rebid
- Making reciprocal arrangements whereby the firm purchases from a supplier who in turn purchases from the firm
- Exaggerating situations to get better deals
- Using company resources for personal gain

One final buyer–supplier relationship deserves special mention. In almost every supply chain, purchasing power plays a role in the relationship between a buyer and supplier. Buyers who represent a large portion of the revenue for a supplier can exact concessions from the supplier that may not be in its best interests. For example, should a powerful buyer force suppliers to take a loss, even for only the short term, on the premise that they, and everyone else, will benefit in the long run? Some would say that was the case when Walmart required all suppliers to invest in radio frequency identification (RFID) technology to track inventories and shipments. Some suppliers, especially those selling commodities with small profit margins, were forced to take a loss to remain a supplier to Walmart. Others would say that in the long run everyone in the supply chain will be better off than before the switch to RFID. Nonetheless, the initial attempts at establishing RFID in Walmart were not well received by suppliers, and their push-back caused the program to falter. Today, Walmart shares in the supplier costs and focuses more on RFID at the item level, especially in apparel, where benefits can be more clearly defined. Privacy watchers, however, are still concerned over the use of RFID because they think the privacy of individual consumers may be compromised as they take products home with the tags attached.

It should be pointed out that ethical issues such as this also confront powerful suppliers, particularly in their contracts with retailers in regard to the exclusivity of their products or control over the ordering policy.

Facility Location

We have already discussed the cost implications of the decision to locate facilities in Chapter 13, "Supply Chains and Logistics." However, major decisions such as facility location have ethical considerations as well. The construction and operation of new facilities may affect the natural environment by disrupting ecosystems, primarily through habitat destruction and increased air, water, and noise pollution. Energy efficiency is also a concern. These considerations raise an ethical dilemma: Should a location based on traditional construction and logistical costs be changed to a more environmentally responsible location if it will increase costs? The location of a facility to avoid the disruption of natural habitats or taking steps to include noise-abatement and air pollution reduction technologies because of local ordinances may increase both start-up as well as operating costs. A balancing act between financial responsibility and environmental responsibility takes place. Locating a facility in a Third-World country to avoid some of the environmental laws in place in more developed countries may be less costly, but is it ethical? However, in some ways, identifying the least costly location may also help the environment. For example, minimizing the total material and personnel travel distances to and from a facility reduces operating costs and increases energy efficiency.

Inventory Management

Inventory policies for independent demand inventories are discussed in Chapter 9, "Managing Inventories." Reducing the order quantity for an item reduces the cycle inventory held in storage while increasing the number of orders per year. The ultimate is a *just-in-time system* (JIT), discussed in Chapter 6, "Designing Lean Systems," where orders of small quantities are placed as they are needed. Imagine a large metropolitan area where most businesses are using JIT systems and the traffic congestion that results from delivery trucks carrying the small order quantities. For example, much of the congestion in Tokyo is attributed to JIT deliveries. While the cost of the inventory system for a given company is minimized in the traditional sense, noise pollution, energy consumption, air pollution, and travel time have increased for the community at large. Once again, there is a balancing act between financial responsibility and environmental responsibility. What can a firm do? Steps can be taken to minimize the material movement to and from the firm by (1) consolidating shipments of items using *a periodic review system* (*P*-system with the same review period for a group of items from the same supplier), or (2) increasing inventory levels by either adjusting the timing of deliveries to avoid rush hours or reducing the total number of shipments. Of course, these remedies increase inventory costs to the firm.

Pitu Cau/Alamy

Rush-hour traffic jams in Tokyo, Japan, are common, as in most large cities. A high proportion of delivery vehicles exacerbates the problem.

Managing Sustainable Supply Chains

How can a firm manage its supply chains to ensure that they are sustainable? Firms might consider the following steps:

1. Develop a *sustainable supply chain framework*. Define what "sustainability" means for the firm in clear terms. Use SA8000:2014 as a guideline for workplace issues.
2. Gather data on the performance of current suppliers and use the same questionnaire to screen potential new suppliers. Use the supply chain sustainability framework as a foundation.

3. Require compliance to the sustainable supply chain framework across all business units, including their dealings with current suppliers and the selection of future suppliers.
4. Engage in active supplier management and utilize all available ethical means to influence their behavior.
5. Provide periodic reports on the impact the supply chains have on sustainability.

Designing and managing a sustainable supply chain is not an easy task. Nonetheless, many firms are making sustainability a major goal of their operations.

LEARNING GOALS IN REVIEW

Learning Goal	Guidelines for Review	MyOMLab Resources
1 Define the three elements of supply chain sustainability.	See the opening paragraphs of this chapter for the challenges managers face to achieve sustainability. See the section "The Three Elements of Supply Chain Sustainability," pp. 599–600, Figure 15.1, and Table 15.1, which contain examples of financial, environmental, and social responsibility involving major companies.	**Video:** Supply Chain Sustainability at Clif Bar & Company
2 Explain the reverse logistics process and its implications for supply chain design.	See the section "Reverse Logistics," pp. 600–603, and study Figure 15.2. Managerial Practice 15.1 shows how Walmart recycles used products and materials.	
3 Show how firms improve the energy efficiency of their supply chains by using the nearest neighbor (NN) heuristic for logistics routes and determining the effects of freight density on freight rates.	See the section "Energy Efficiency," pp. 603–608. Be sure you understand the NN heuristic, Example 15.1, and Solved Problem 1. Study the break-even approach to identifying break-even weights for the shipment of goods, Table 15.2, Example 15.2, and Solved Problem 2.	
4 Explain how supply chains can be organized and managed to support the response and recovery operations of disaster relief efforts.	The section "Disaster Relief Supply Chains," pp. 608–611, contains a discussion of the organization of disaster relief supply chains and the role of supply chain managers in disaster relief efforts. Figure 15.4 shows the three major disaster relief operations that supply chains must support.	
5 Describe the ethical issues confronting supply chain managers.	The section "Supply Chain Ethics," pp. 611–612, discusses the nature of the ethical issues that supply chain managers face and how they can deal with them.	
6 Explain how a firm can manage its supply chains to ensure they are sustainable.	See the section "Managing Sustainable Supply Chains," pp. 612–613, for five steps managers can take to ensure that their supply chains are sustainable.	

Key Equation

Energy Efficiency

Break-even weight:

$$A = \text{lower weight bracket}$$
$$B = \text{next highest weight bracket}$$
$$C = \text{freight rate relative to } A$$
$$D = \text{freight rate relative to } B$$
$$x = (BD)/C$$

Key Terms

carbon footprint 603
closed-loop supply chain 601
environmental responsibility 599
financial responsibility 599
humanitarian logistics 599
intermodal shipments 608
nearest neighbor (NN) heuristic 604
reverse logistics 600
route planning 603
SA8000:2014 611
shortest route problem 603
social responsibility 599
sustainability 598
traveling salesman problem 603

Solved Problem 1

MyOMLab Video

Greenstreets Recycling, Inc., collects used motor oil from several collection sites around the Greater Stanford area. To minimize the use, and thereby the cost, of its labor, vehicle, and energy resources, the company is interested in locating the shortest route that will allow its collection vehicle to visit each collection site exactly once. The following table provides the travel distances in miles between each site. Note that the company's recycling facility is located at site A.

From/To	A	B	C	D	E	F
A (depot)	–	25	50	48	41	60
B	25	–	35	22	23	43
C	50	35	–	25	47	65
D	48	22	25	–	24	40
E	41	23	47	24	–	21
F	60	43	65	40	21	–

Provide an efficient route for the collection vehicle.

SOLUTION

a. Begin at the recycling facility (site A) and proceed to its nearest neighbor (site B) which is 25 miles away.
b. From site B proceed to its nearest unvisited neighbor. Proceed from B to D—distance 22 miles.
c. From site D proceed to site E—distance 24 miles.
d. From site E proceed to site F—distance 21 miles.
e. From site F proceed to site C (the only remaining unvisited site)—distance 65 miles.
f. From site C return to A—distance 50 miles.

The completed route is A–B–D–E–F–C–A with a total distance traveled of 207 miles $(25 + 22 + 24 + 21 + 65 + 50)$.

To see if a better solution exists, the nearest neighbor heuristic should be repeated using each city in turn as the starting point.

City B: B–D–E–F–A–C–B with a total distance of $(22 + 24 + 21 + 60 + 50 + 35) = 212$ miles
City C: C–D–B–E–F–A–C with a total distance of $(25 + 22 + 23 + 21 + 60 + 50) = 201$ miles
City D: D–B–E–F–A–C–D with a total distance of $(22 + 23 + 21 + 60 + 50 + 25) = 201$ miles
City E: E–F–D–B–A–C–E with a total distance of $(21 + 40 + 22 + 25 + 50 + 47) = 205$ miles
City F: F–E–B–D–C–A–F with a total distance of $(21 + 23 + 22 + 25 + 50 + 60) = 201$ miles

Note that the solutions using cities C, D, and F as the starting point all provide the shortest total distance. Thus, with the recycling facility at site A, the collection vehicle should proceed to F then E then B then D then C and finally back to A with a total distance traveled of 201 miles. It should also be noted that since the distances are symmetric, a route of reverse order, A–C–D–B–E–F–A, provides the same total distance traveled.

Solved Problem 2

Kayco Stamping in Ft. Worth, Texas, ships sheet metal components to a switch box assembly plant in Waterford, Virginia. Each component weighs approximately 25 pounds, and 50 components fit on a standard pallet. A complete pallet ships as freight class classification 92.5. Use Table 15.2 to calculate the shipment cost for the following demand quantities and calculate the shipping cost per component.

a. 3 pallets

b. 13 pallets

SOLUTION

a. At 3 pallets, or 150 pieces, the shipping weight $= 150 \times (25 \text{ pounds}) = 3{,}750$ pounds

At a freight classification of 92.5, using Table 15.2, the break-even weight $= 50(28.64)/37.56 = 38.13$ or 3,813 pounds, thus the shipment does not qualify for the lower rate.

Total shipping cost $= 37.5(37.56) = \$1{,}408.50$

The per-component shipping charge is $\$1{,}408.50 / 150 = \$9.39$

b. At 13 pallets, or 650 pieces, the shipping weight $= 650 \times (25 \text{ pounds}) = 16{,}250$ pounds

At a freight classification of 92.5, using Table 15.2, the break-even weight $= 200(18.87)/28.38 = 132.98$ or 13,298 pounds, thus the shipment qualifies for the lower rate.

Total shipping cost $= 162.5(18.87) = \$3{,}066.38$

The per-component shipping charge is $\$3{,}066.38 / 650 = \$4.72$.

Discussion Questions

1. Supply chain sustainability is about combining elements of social responsibility, financial responsibility, and environmental responsibility. The chapter opener discusses how FedEx actively participated in transporting humanitarian aid to specific areas in the Philippines. Define each element of supply chain sustainability and illustrate how FedEx contributed to at least one segment of supply chain sustainability.
2. Designing supply chains that are energy efficient and environmentally responsible helps a firm achieve a competitive priority of low-cost operations, which supports the firm's financial responsibility to its shareholders. Explain how focusing on energy efficiency can pose some ethical dilemmas for supply chain managers.
3. As more firms entertain the option of developing reverse logistics supply chains, explain the financial implications they should consider.
4. Supply chain sustainability is a concept that has recently emerged in answer to global concerns about climatic changes and ethical considerations when Western firms came under activists' scrutiny while doing business in certain developing economies. Consequently, suppliers need to be carefully selected prior to doing business with them. Identify all the areas that need to be taken into account when selecting a new supplier and discuss how they differ from the standards in your own country.

Problems

The OM Explorer and POM for Windows software is available to all students using the 11th edition of this textbook. Go to **http://www.pearsonglobaleditions.com/krajewski** to download these computer packages. If you purchased MyOMLab, you also have access to Active Models software and significant help in doing the following problems. Check with your instructor on how best to use these resources. In many cases, the instructor wants you to understand how to do the calculations by hand. At the least, the software provides a check on your calculations. When calculations are particularly complex and the goal is interpreting the results in making decisions, the software entirely replaces the manual calculations.

Energy Efficiency

1. On a daily basis, the Vampire Van is dispatched from Maplewood Hospital to pickup blood and platelet donations made at its local donation centers. The distances in miles between all locations may be found in Table 15.3.
   a. The Vampire Van travels from Maplewood Hospital (A) to (B) to (C) to (D) to (E) and then returns to the hospital (A). What is the total number of miles that the van must travel using this route?
   b. Using Maplewood Hospital as the beginning location, create a route using the NN heuristic. What is the total number of miles that the van must travel using this route?
   c. Using Valley Hills (E) as the beginning location, create a route using the NN heuristic. What is the total number of miles that the van must travel using this route?

TABLE 15.3 MILEAGE DATA FOR VAMPIRE VAN

From/To	Maplewood Hospital (A)	City Center Donation Site (B)	Westbrook Donation Site (C)	Municipal Park Donation Site (D)	Valley Hills Donation Site (E)
Maplewood Hospital (A)	–	3.0	3.5	4.0	4.1
City Center Donation Site (B)	3.0	–	6.1	7.0	4.3
Westbrook Donation Site (C)	3.5	6.1	–	4.2	3.6
Municipal Park Donation Site (D)	4.0	7.0	4.2	–	7.2
Valley Hills Donation Site (E)	4.1	4.3	3.6	7.2	–

2. Royal Seafood delivers fresh fin and shellfish to specialty grocery stores in the state of Oregon. The company packs a delivery truck in Corvallis and then drives in one single route to its five customers spread throughout the state. The distances in miles between all locations may be found in the table below.

From/To	Corvallis (A)	Roseburg (B)	Bend (C)	Baker (D)	Lakeview (E)	Burns (F)
Corvallis (A)	–	225	234	233	169	189
Roseburg (B)	225	–	159	244	265	168
Bend (C)	234	159	–	253	246	197
Baker (D)	233	244	253	–	153	287
Lakeview (E)	169	265	246	153	–	171
Burns (F)	189	168	197	287	171	–

   a. Propose an efficient route by using the NN heuristic with Corvallis as the starting city. What is the total distance traveled?

   b. Use the NN heuristic to calculate five routes, each starting from one of Royal Seafood's customer's location. What is the best route for Royal Seafood?

3. On Thursdays, Traxis Consolidated delivers liquid oxygen to its industrial customers in northern Michigan. The table below provides the driving time in minutes among all customers and the Traxis liquid oxygen depot location.

From/To	A (depot)	B	C	D	E	F	G	H
A (depot)	–	73	65	47	84	32	29	23
B	73	–	38	56	78	30	27	51
C	65	38	–	69	54	57	67	45
D	47	56	69	–	43	61	33	52
E	84	78	54	43	–	37	46	62
F	32	30	57	61	37	–	35	47
G	29	27	67	33	46	35	–	18
H	23	51	45	52	62	47	18	–

   a. Currently, Traxis travels from the depot (A) to (F) to (G) to (D) to (E) to (H) to (B) to (C), then returns to (A). What is the total driving time using this route?

   b. Using the depot (A) as the beginning location, create a route using the NN heuristic. What is the total driving time using this route?

   c. Use the NN heuristic to calculate seven routes, each starting from one of Traxis's customer's locations. What are your conclusions?

4. Big Jim plows snow for five residential customers in northern New Hampshire. Placing a Cartesian coordinate system on a map of his service area, with his home at the origin (A), Big Jim located his five customers at coordinates: B (10,40); C (22,20); D (35,37); E (40,25); F (50,40). He has two ways to measure distances between his customers: Euclidean and rectilinear (see Chapter 13, "Supply Chains and Logistics" and the section on load–distance method for the definitions of these measures). He is wondering if his method of measuring distances will affect the sequence of customer locations he must visit to minimize his energy costs.

   a. Use the NN heuristic to locate the best route for Big Jim, assuming that he is interested in minimizing Euclidean distances.

   b. Use the NN heuristic to locate the best route for Big Jim, assuming that he is interested in minimizing rectilinear distances.

5. Helping Harvest is a food bank in the Greater Miami area that collects food donations from local grocery stores and transports them back to a distribution center for sorting and transfer to local food kitchens that feed needy clients. Tight budgets and environmental concerns require that both fuel and driver resources be used sparingly. Thus, Mr. Vivek, Helping Harvest's general manager, would like to ensure that collection vehicles are routed most efficiently. The table below provides the driving distance in miles among the depot (the distribution center from where truck begins and ends its route) and the five stores that donate food.

From/To	Depot	Store A	Store B	Store C	Store D	Store E
Depot	–	10	24	60	40	26
Store A	10	–	34	46	35	44
Store B	24	34	–	48	20	15
Store C	60	46	48	–	15	35
Store D	40	35	20	15	–	12
Store E	26	44	15	35	12	–

Currently, the Helping Harvest truck travels the following route Depot–Store A–Store B–Store C–Store D–Store E–Depot.

a. Use the NN heuristics to find a shorter route and calculate the savings in miles traveled per day.

b. The manager at Store B would like the Helping Harvest truck to pick up from her store as early as possible. How many miles does the constraint of visiting Store B first add to the route selected in part a?

6. Revisit the Helping Harvest problem in Problem 5. Assume that due to truck capacity constraints, not all stores can be visited in one route. Use the NN heuristic to develop two routes, one that picks up from Stores A and B and one that picks up from C, D, and E in two separate trips. How many miles does this capacity constraint add to the truck's daily miles of travel?

7. Professor Gaffney needs to ship 800 pounds of laboratory equipment to a colleague across country. Due to limited departmental funds, Dr. Gaffney would like to minimize total shipment costs. Currently, the freight classification is 85. However, a local equipment manufacturing company is willing to specially package the equipment in order to drop the freight classification to 50. Use Table 15.2 to calculate the break-even cost of using this service.

8. Sampson Industries is very concerned about the cost of shipping products on a daily basis to its distributor. Sampson is considering consolidating daily shipments into weekly or even monthly deliveries. Currently, every month Sampson makes 20 shipments of 1,500 pounds each. Use Table 15.2 to calculate the monthly cost of Sampson's current shipping practice and then calculate the cost of consolidating to 10, 5, 2 and then 1 shipment per month. Sampson believes that the freight classification will stay at 60 irrespective of consolidation.

9. Arts N Crafts Industries manufacturers high-end light fixtures, which it sells internationally. The company is responsible for paying for shipping its product to a distributor located in Atlanta, Georgia. Due to the high cost of shipping, the company is considering shipping its products unassembled, but will include detailed assembly instructions in each package. By shipping unassembled products, Arts N Crafts will be able to shrink the size of its cartons and thereby increase the number of products per pallet from 16 (4 rows of 4) to 25 (5 rows of 5). Note that this change will not appreciably increase each product's 8-pound shipping weight. Furthermore, since individual fixtures will be packed more tightly, they will be less susceptible to damage and easier to handle. Thus, the company expects the freight class to decrease from 85 to 70. Currently the company ships 400 units per week.

a. Using Table 15.2, assess the impact of the proposed change in packaging on weekly shipping cost.

b. How will your analysis change if demand for the product increases to 500 units per week?

10. Microtech Incorporated has decided to package its cell phone in a smaller, recyclable package. Additionally, the company will discontinue the practice of shipping each phone with a 250-page user manual and instead will make the manual available online. These changes will result in a lighter, but more difficult package for shippers to handle. The weight of each packaged phone has dropped from 1.2 pounds to 0.5 pounds as a result of these changes and the freight classification has worsened from 55 to 70. Use Table 15.2 to calculate the difference in Microtech's monthly shipping charges if the company ships 10,000 phones per month.

VIDEO CASE Supply Chain Sustainability at Clif Bar & Company

When Gary Erickson started out on one of his typical long-distance bike treks in 1990, he expected to have a great ride. What he did not expect was to come home with the idea for a sports nutrition energy bar that became the genesis of Clif Bar & Company.

After consuming most of his supply of Power Bars part way through the 175-mile ride, Erickson could not face the prospect of consuming another one. Instead, he figured he could come up with something better. Something sports enthusiasts would not mind eating in quantities while out on the road or the trail. The result? The CLIF® BAR, an all-natural combination of grains, nuts, and fruit, with far more taste appeal than the standard energy bar of the time.

Today, the Berkeley, California-based company has over 100 stock-keeping units, or SKUs, in its product mix, including numerous flavorful versions of the original CLIF BAR plus brands such as LUNA®, The Whole Nutrition Bar for Women™; CLIF Kid Organic ZBaR™, The Whole Grain Energy bar for kids; CLIF Mojo™, The Sweet & Salty Trail Mix Bar; and CLIF Nectar®, an organic fruit and nut bar made with just five ingredients. CLIF BARs were originally distributed through cycling shops and other niche retail outlets but can now be found in a wide variety of retail outlets in the United States, such as Whole Foods, Trader Joe's, REI, and even your local grocery store.

From the beginning, CLIF BARs were made from wholesome ingredients. Yet as Erickson looked at the ingredients being sourced for CLIF BAR, he realized that making a healthy food product and sourcing ingredients from farmers, ranchers, and cooperatives using organic growing techniques was a "natural" fit. The company made a commitment to both sustainable growing techniques and using only organic raw ingredients back then, and by 2003, had made CLIF BAR 70 percent certified organic. Since then, six of Clif Bar & Company's CLIF and LUNA brands are now made with 70 percent organic ingredients or more.

The impact on the supply chain for sourcing organic ingredients is tremendous. First, there is a limited—but growing—number of organic growers for the ingredients Clif Bar uses. Second, growers who do not use pesticides, herbicides, and genetically modified plants are sometimes at risk of producing lower crop yields. Third, it can be more costly to store the ingredients. And fourth, as more companies commit to environmentally responsible programs and organic ingredients, competition is great for the available global supply.

The company's forecasters and planners work hard to manage both the raw ingredient inventory flows from upstream suppliers and the finished goods flows to downstream customers to be sure products are available in the right quantities and right locations. Ordering on raw materials and packaging materials is aggregated to provide efficient sourcing. Production is planned, based on both input and output forecasts, to maximize customer service and minimize inventory. Several times a year, production plans are shared with business partners at all points of the supply chain to make sure the flow of ingredients and products is smooth, and that inventories do not accumulate at any point in the supply chain beyond planned volumes. Monthly forecasts and changes to plans also are communicated to all supply chain partners.

Clif Bar & Company managers know that consumers' tastes for products change regularly, so new flavors and brands are periodically introduced into the various brands. Likewise, flavors are sometimes retired to make room for new ones. As the company's research and development team prepares to move a new product idea from the test kitchen to the manufacturing plant, supply chain managers must get to work assuring any new ingredients can be procured.

As a smaller and privately owned company, Clif Bar does not own its manufacturing plants and distribution centers, and relies on contractual agreements with outsourcers in the United States. These supply chain business partners are carefully chosen for their ability to manufacture and distribute Clif Bar's products, their commitment to quality, and their alignment with Clif Bar's own value system. This value system, referred to as the company's "Five Aspirations," holds that Clif Bar & Company will work toward sustaining its people, brands, business, community, and the planet. Greg Ginsburg, Vice President of Supply Chain, wants to be sure all parts of the supply chain—owned or not—are in agreement with these aspirations. "We look at their energy sourcing, labor practices, and workplace environments. And where we source products from small cooperatives, we'll go as far back as possible to assure those tiny growers know about our expectations," says Ginsburg.

QUESTIONS

1. In what ways does Clif Bar have a sustainable supply chain?
2. Regarding financial responsibility, what business risks does Clif Bar & Company face with so many parts of its supply chain outsourced?
3. What issues or risks to sustainability could Clif Bar & Company encounter if it chose to expand to international markets?