13

SUPPLY CHAIN LOGISTIC NETWORKS

Airbus SAS

NICHOLAS KAMM/AFP/Getty Images

Airbus CEO and President Fabrice Bregiere and an employee put up a sticker on the tail of the first Airbus A321 to be assembled during the inauguration of Airbus' first U.S. manufacturing facility in Mobile, Alabama. European jetmaker Airbus inaugurated its first U.S. plant in a move to wrest a chunk of Boeing's domination of the domestic aircraft market including lucrative Pentagon contracts. Airbus expects to eventually assemble 40–50 of its single-aisle A320 family every year from its new plant, built on the site of a World War II bomber support base.

In 2012 Airbus SAS, a division of Airbus Group SE, a $65B manufacturer of civilian aircraft, had final assembly plants in Toulouse, France; Hamburg, Germany; Seville, Spain; and Tianjin, China. The location of final assembly plants in the aerospace industry is a strategic decision because major components such as engines, fuselages, cockpits, wings, and vertical tails must be transported to the site, and then the final product must be delivered to the customers. Airbus has a huge backlog of orders for the fuel-saving A320 aircraft, a versatile twin-engine plane that is used by hundreds of airlines for both short-haul and intercontinental routes. An A320 takes off and lands in the world every 2 seconds. More than 75 airlines have purchased more than 4,300 new-version A320s, and yet there is a backlog of 1,200 conventional A320s. So Airbus SAS decided to expand capacity and build its first U.S.-based aircraft manufacturing center in Mobile, Alabama, at a cost of $600 million. The center consists of a final assembly line (FAL), a logistics building, and a service building totaling 425,000 square feet. The FAL is designed to build the A320 family (A318, A319, A320, and A321) of single-aisle aircraft. The facility has state-of-the-art technology, and is designed to ultimately achieve Rate 8, or eight planes a month.

Why choose the United States, and specifically Mobile, Alabama, for the new manufacturing center? There were several considerations that prompted the decision to locate the new facility in this location. First, it reinforces and regenerates Airbus's sales in the United Sates. For example, Airbus estimates that the U.S. market will need 4,730 new single-aisle aircrafts over the next 20 years, and Airbus expects to get orders for 40 percent of that market. That implies selling an average of 94 extended-body single-aisle aircraft (A321s) a year in the United States over the next two decades. The market boost in the United States, however, is that Airbus is not just using U.S. suppliers; it can now claim that its best-selling products are "Made in America." Second, there are also supply chain advantages in locating closer to its U.S. customers. The logistics costs of delivery of the final product from a FAL to the customer are obviously lower. At the same time, logistics costs are further reduced by the fact that smaller aerospace companies that supply parts and components tend to locate near the manufacturing center. For example, the Irish aircraft painting company, MAAS Aviation, has embedded itself within the Airbus Mobile paint shop, and other subcontractors are expected to follow soon. Finally, the presence of a large civil aerospace factory on U.S. soil increases Airbus's credentials and clout for future defense contracts from Washington. A flight-test center also opens the possibility of cooperation with NASA on aeronautical research.

There were also several key considerations for choosing Mobile, Alabama, for the new facility. First, beyond the $158 million offered as incentives by the state of Alabama, Mobile is the home of the Mobile Aeroplex at Brookley, which has been redeveloped from a former military base. It has a 10,000-foot-long runway, and is located just 4 miles from the city. It is also about the same distance from the Port of Mobile, a large deep-water seaport. Airbus can transport A320-family major assemblies such as fuselage sections from Hamburg, cockpits from France, wings from England, and vertical tail sections from Spain and truck them in less than an hour to the assembly line. Second, Mobile offers a nonunionized workforce that allows Airbus a degree of flexibility to adjust production rates and work assignments that would not be possible with strong labor unions. The plant complex will ultimately employ 1,000 workers, 30 percent of them being U.S. veterans with excellent skills for the aerospace industry. As part of the Alabama incentive package, Airbus has a $52 million onsite training facility where workers are trained at state expense. Finally, Airbus and Mobile have a good relationship that was developed from past dealings. Airbus's proposal to build air tankers for the U.S. airforce was lost to Boeing after a long battle, and Mobile, which was chosen by Airbus for the location of the proposed manufacturing site, played a major role in developing the proposal. So when it came time to find a good U.S. location, Mobile was at the top of the list. As one executive noted at the inauguration of the plant: "If they wanted low-cost labor, they would have just set up in Mexico."

The plant began assembly of its first plane, an A321, in July 2015 and delivered it to JetBlue in April 2016. By September 2016 it delivered its tenth U.S.-built airliner.

Sources: Tim Robinson, "Sweet FAL Alabama," Royal Aeronautical Society (September 16, 2015); Austin Weber, "Airbus Assembly Plant Lands in Alabama," Assembly (January 5, 2016); Chris Kjelgaar, "Airbus Has a Sweet Home for U.S. A320 Production," **http://www.ainonline.com/aviation-news** (February 12, 2016); Alwyn Scott and Tim Hepher, "Aiming for U.S. Market, Airbus Delivers First U.S.-Made Jetliner," **http://www.reuters.com/aricle/us-airbus-usa-idSKCN0XM1SO** (April 26, 2016); Lawrence Specker, "Mobile's Airbus Plant Delivers 10th U.S.-Built Jetliner," **http:/www.al.com** (September 19, 2016).

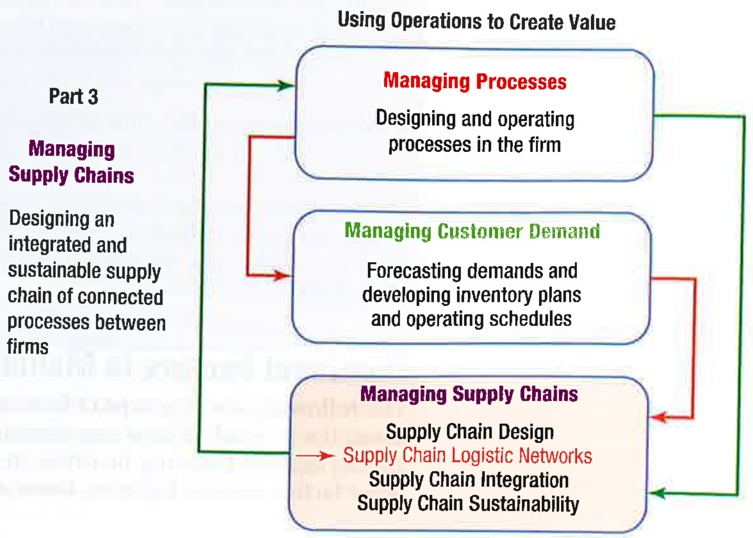
LEARNING GOALS *After reading this chapter, you should be able to:*

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.

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.

Firms like Airbus SAS 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. Once there is a decision on a supply chain design that reflects the competitive priorities of a firm, the location of the facilities in the supply network becomes critically important. Location choices can therefore 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.

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 Airbus located its final assembly line complex in Alabama, the economic environment of the state, the proximity of suppliers and customers, 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 the Internet 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, the existing infrastructure, and monetary incentives were dominant factors affecting the decision to locate the Airbus plant in Mobile, Alabama. 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 Airbus SAS, 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 onsite but also to the employees that a firm hopes will transfer to or 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 added a new 256,000-square-foot paint facility in 2016.

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, "Supply Chain Sustainability."

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 rooftop 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.

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.

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 14, "Supply Chain Integration" and the section "Inventory Placement" in this chapter).

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 Airbus plant in Alabama 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.

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 30 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 3 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.

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.

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

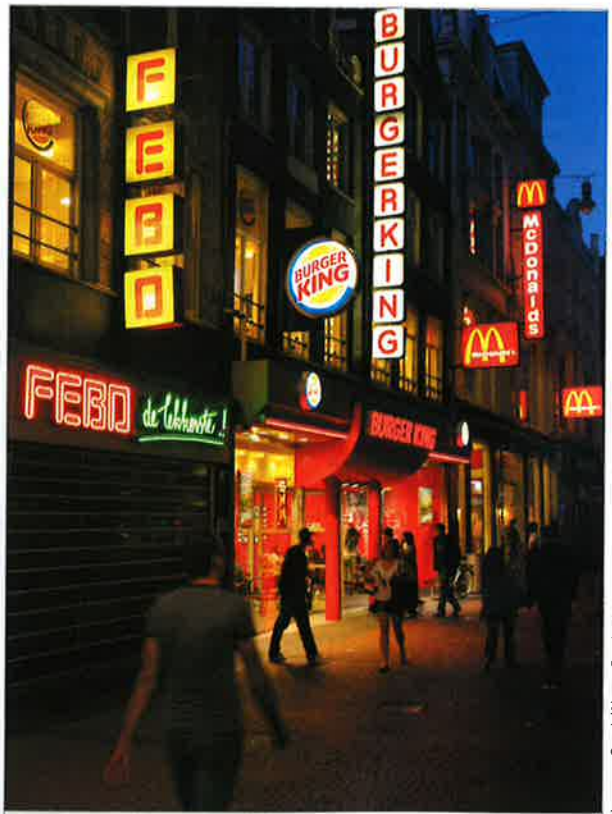
Kevin Foy/Alamy Stock Photo

Proximity to customers and providing a service they want are keys to a successful location decision. Here office workers are queuing outside a trendy deli sandwich shop during their lunch break in Dublin, Republic of Ireland.

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.



Lourens Smak/Alamy Stock Photo

The fast-food industry has long practiced the strategy of critical mass. Here, fast-food restaurants are clustered on the Nieuwendijk in the city center of Amsterdam, the Netherlands."

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

load–distance method

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

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.

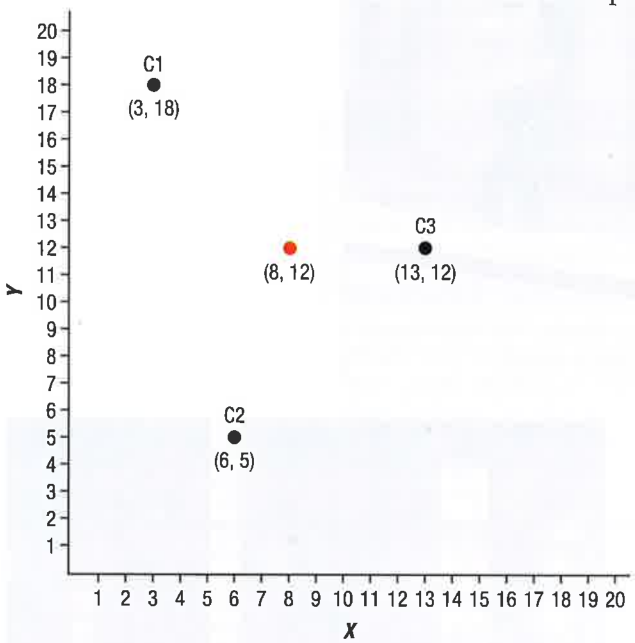
Distance Measures

Euclidean distance

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

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



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

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

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

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.

MyLab Operations Management

Tutor 13.1 in MyLab Operations Management 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 traveling 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

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 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:

center of gravity

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

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

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 shows how to find the center of gravity using the load-distance method.

Lynnette Peizer/Alamy Stock Photo

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.

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

MyLab Operations Management

Tutor 13.2 in MyLab Operations Management provides another example on how to calculate the center of gravity.

MyLab Operations Management

Active Model 13.1 in MyLab Operations Management provides insight into the center of gravity method.

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 here:

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)

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 here:

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

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

$$= 7{,}504$$

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

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

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

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

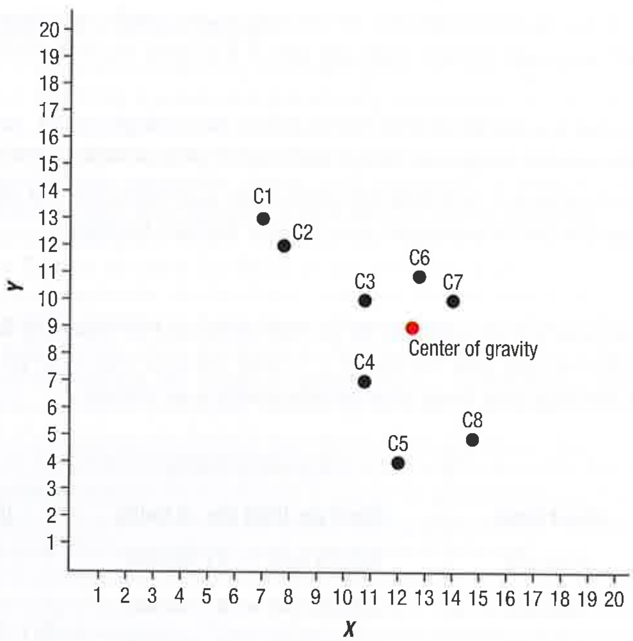


FIGURE 13.2
Center of Gravity for Electric Utilities Supplier

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"). 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 demonstrates the use of break-even analysis for a location decision involving 4 proposed sites.

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

MyLab Operations Management

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

MyLab Operations Management

Tutor 13.3 in MyLab Operations Management 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.

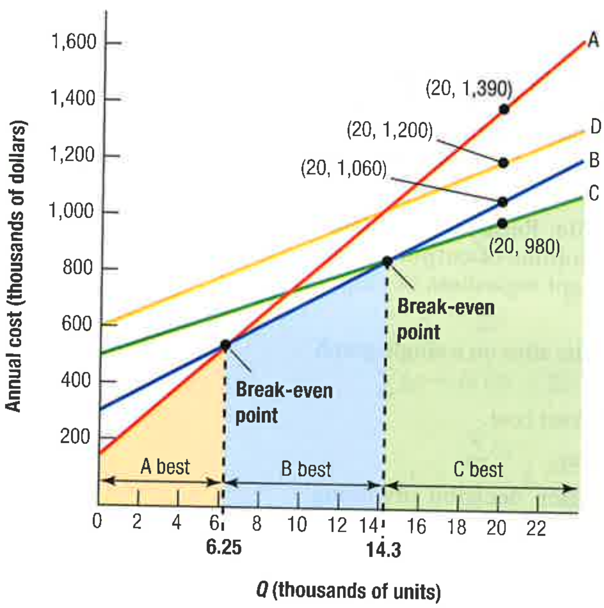
Step 1. Plot the total cost curves for all the communities on a single graph. Identify on the graph the approximate volume range over which each community provides the lowest cost.

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:

Community	Fixed Costs	VARIABLE COSTS (Cost per Unit) (No. of Units)	TOTAL COST (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**
Break-Even Analysis of Four Candidate Locations

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	

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 nonquantitative 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.

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," and textbooks covering quantitative methods and management science.

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

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 in 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.

▼ **FIGURE 13.4**
Initial Tableau

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

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"), 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 uses the transportation method to find the optimal shipping pattern for a proposed new plant in Atlanta.

EXAMPLE 13.3 Interpreting the Optimal Solution

▼ 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

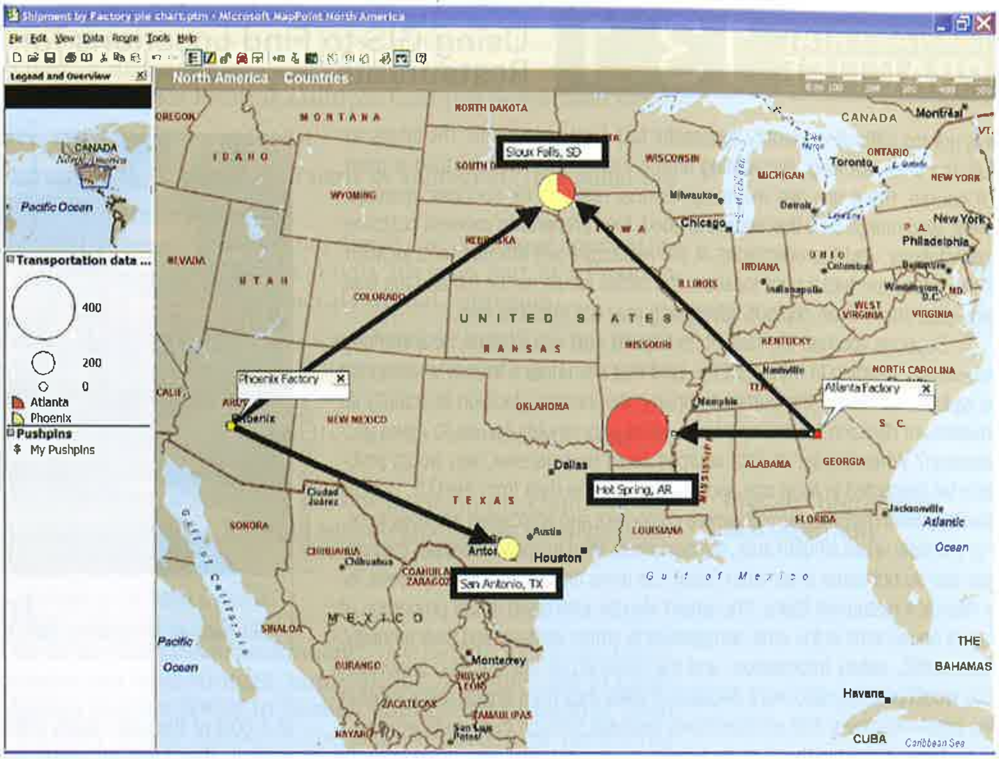
The optimal solution for the Sunbelt Pool Company, found with POM for Windows, is shown in Figure 13.5. Figure 13.5(a) displays the data inputs, with the cells showing the unit costs, the bottom row showing the demands, and the last column showing the supply capacities. Figure 13.5(b) shows how the existing 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.

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 **yellow** and the Atlanta plant and its shipments are represented in **red**. 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.



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

Geographical Information Systems

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.

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.

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 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 Using GIS to Find Locations for Fast-Food Restaurants

It is not too difficult to identify successful fast-food restaurants. The tables are full, the lines are long, the waiting time is reasonable, and the food is good. Of course, there are two major operational reasons for success: management, who makes sure that service is good, food preparation exceeds customer expectations, and the operations of the restaurant are efficient; and location. If the restaurant had a poor location, the tables would not be full and the lines would be short. Even copious advertising may not right the ship.

Suppose you had the task of finding the next site location for a Wendy's restaurant. Keeping in mind that the land that sits under a Wendy's restaurant is typically owned by the parent company, the location decision is actually an investment decision for the long term. What data would you use to make your decision? While the list of data sources could be extensive, you would probably be interested in local age and average income data from the U.S. Census Bureau, which helps determine where customers and employees are likely to be. For example, in an affluent area, the customers tend to spend more per transaction but do not come in as often. Also, it is more difficult to find employees for a Wendy's restaurant there. You would also be interested in the proportion of family households in the area, as opposed to empty nesters, and their ethnicity. Auto traffic, safety information, and the commercial mix are also important. You would probably also want decades of sales data from similar restaurants in the area—numbers that are commonly available through third-party vendors.

Now, armed with all of that data, what are you going to do with it? Perhaps do as Wendy's, Starbucks Coffee, Culver's, and Chick-fil-A do: Use GIS to assist in their location-based analytics because of its capability to represent spatial data graphically with data overlays. It makes the geographical data easier to understand than if you were using GPS coordinates on a spreadsheet. In GIS, demographic information is stored and collected as thematic layers, linked by geography, and pulled in and out to make location decisions much easier. For example, Starbucks used GIS to find a site in Nanjing, China. One of a host of thematic layers critical to the decision was the foot traffic from several office buildings under construction. Once that data was overlaid on a map of the area, viable sites for the new Starbucks became evident. In the United States, in conjunction with its effort to add beer and wine to store menus, Starbucks used GIS to find locations with two thematic layers: high local spending patterns and a large number of wine-away-from-home drinkers. Now you can find beer and wine on the Starbucks menus of higher-end Reserve and Roastery restaurants in—guess where?—affluent neighborhoods with ample wine-away-from-home drinkers.

E.Westmacott/Alamy Stock Photo

Wendy's uses GIS to locate its fast-food restaurants, such as this one on 6th Avenue, Manhattan, New York City.

Sources: Neal Ungerleider, "How Fast Food Chains Pick Their Next Location," **https://www.fastcompany.com** (August 25, 2014); Mohana Ravindranath, "Wendy's Uses Mapping Software from California Firm ESRI to Pick New Locations," *The Washington Post* (August 7, 2014); "Restaurants Optimize Site Locations: Wendy's, Arby's, Culver's," **http://www.esri.com/esri-news/arcnews** (Spring 2013); "What Is Geographic Information Systems (GIS)," *GISGeography* (January 22, 2017).

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 Waze, 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. Websites 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 Business Analyst (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 come with the software itself instead of having to be purchased separately from the GIS vendor in many other systems. MyLab Operations Management has three videos on how MapPoint can be used to make location decisions.

MyLab Operations Management

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 geo-demographic 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 MyLab Operations Management.

MyLab Operations Management

Inventory Placement

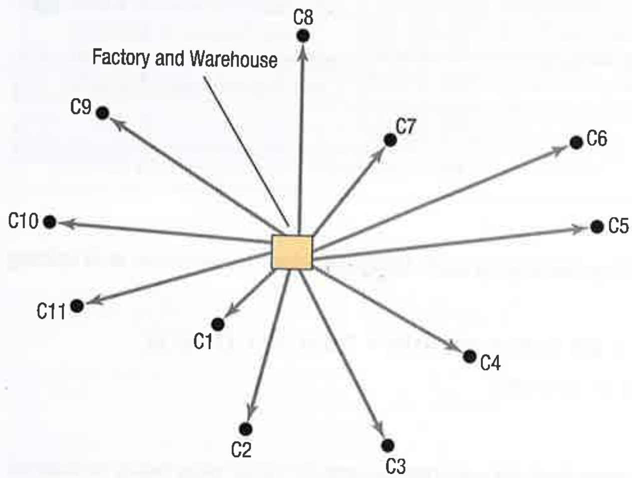
A fundamental supply chain design decision that affects performance is where to locate an inventory of finished goods. Placing inventories can have strategic implications, as in the case of international companies locating *distribution centers* (DCs) in foreign countries to preempt local competition 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 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.

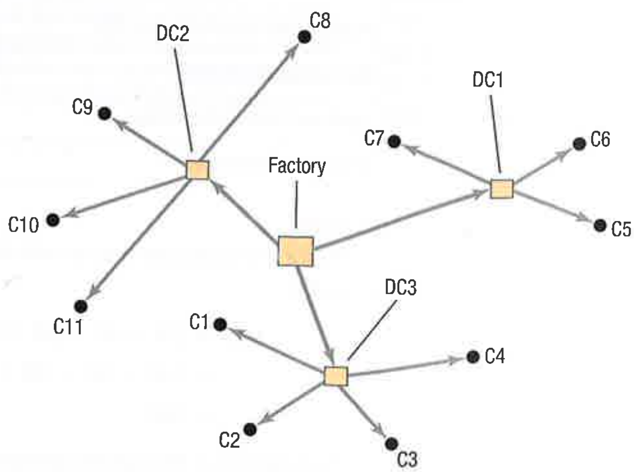
centralized placement
Keeping all the inventory of a product at a single location such as at a firm's manufacturing plant or a warehouse and shipping directly to each of its customers.

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.



▲ FIGURE 13.7
Centralized Placement with Inventory Pooling



▲ FIGURE 13.8
Forward Placement of Inventories

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"). 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**

MyLab Operations Management

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

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?

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	MyLab Operations Management Resources
1 Identify the factors affecting location choices.	See the section "Factors Affecting Location Decisions," pp. 552–555. 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. 555–559, discusses the distance measures, the load–distance metric, and the calculations for the center of gravity. Study Solved Problem 1, which shows how to employ 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. 559–560, 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. 561–563, 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. 563–565, 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," p. 565, and study Figures 13.7 and 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. 566–567, 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