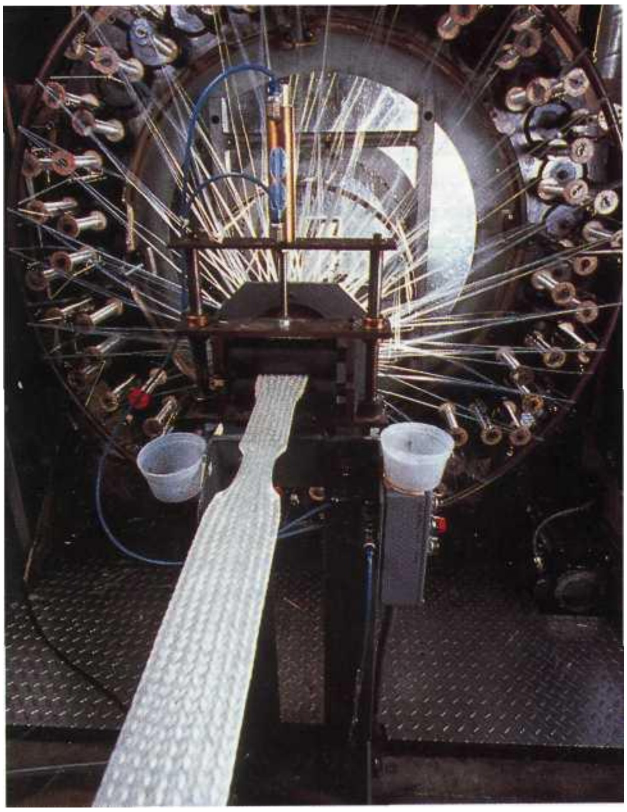
CHAPTER 05 PROCESS DESIGN

INTRO

K2 Corporation – manufacturer of skis

Once a firm has identified its market niche and the competitive priorities that spell success, it must design an operations system to meet its needs. K2 Corporation, the largest U.S. manufacturer of Alpine skis, chose an intermediate positioning strategy that allowed customization and high-volume production of some products. High-performance design and quality became competitive priorities. The next step was to design a manufacturing process that would deliver.



For customization, K2 installed general-purpose machinery that allowed easy changeovers from product to product. For design and quality, they invested in a triaxial braiding process that gave designers greater control over longitudinal and torsional flexes in the skis. K2's plant has five departments: parts, molding, base finishing, graphics, and finishing. Molding has 52 general-purpose presses, some dedicated to high-volume products. Within base finishing and finishing, machines are arranged to use the machine sequences common to most products.

The revolutionary triaxial braiding process at K2 creates a tight fiberglass casing around a wood core, producing an extremely strong and durable ski.

Why is process design important?

One essential question in the design of a production system is, *How* should we make our products or provide our services? The question is obvious, but the answer involves many different choices in selecting the best mix of human resources, equipment, and materials. Process design choices are strategically important. Wrong choices can affect an organization's ability to compete over the long run. Process design directly affects productivity because much of the input of the output/input ratio is set during process design. However, process design choices are not made once and for all – process design is an ongoing activity. Its principles apply to both first-time and redesign choices.

What are we going to study?

We begin by defining and considering four facets of process design: capital intensity, resource flexibility, vertical integration, and customer involvement. We turn next to some basic techniques for analyzing new and existing processes: capital budgeting, flow diagrams, process charts, and multiple activity charts. In Chapter 6 we explore technological advances, an important aspect of process design, and the ever-widening array of choices they present. Chapter 7 covers the other critical aspect of process design: job design and work teams.

WHAT IS PROCESS DESIGN?

Process design is the selection of inputs, operations, work flows, and methods for producing goods and services. Input selection includes choosing the mix of human skills, raw materials, and equipment consistent with an organization's positioning strategy and its ability to obtain these resources. Operations managers must determine which operations will be performed by workers and which by machines. They also determine the transformations (see Fig. 1.1) that will be used to meld human beings and machines into cohesive production processes. Process design or redesign decisions must be made when:

- A new or substantially modified product or service is being offered.
- Competitive priorities have changed.
- Demand volume for a product or service is changing.
- Current performance is inadequate.
- Competitors are gaining by using a new process or technology.
- The cost or availability of inputs has changed.

Not all these situations lead to a change in the current process. Sometimes the costs of change clearly outweigh the benefits. Whether or not changes are made, process design must take into account other choices concerning product and service design, quality, capacity, and layout. Process design decisions also depend on where products and services are in their life cycle, on competitive priorities, and on positioning strategy. Ethics and the environment are other considerations, as Managerial Practice 5.1 shows.

FACETS OF PROCESS DESIGN

Whether considering processes for offices, service industries, or manufacturers, operations managers must weigh four common facets of process design. **Capital intensity** is the mix of equipment and human skills in a production process; the greater the relative cost of equipment, the greater is the capital intensity. **Resource flexibility** is the ease with which equipment and employees can handle a wide variety of products, output levels, duties, and functions. **Vertical integration** is the degree to which a firm's own production system handles the supply chain from raw materials to final consumer. The more a firm's production system manages the supply chain, the greater is the degree of vertical integration. **Customer involvement** reflects how much and in what ways the customer becomes a part of the production process.

Managerial Practice 0.1 . Process Design: Ethics and the Environment

Ethics

Wall Street has been in love with Nucor Corporation, which has transformed itself from a backwater fabricator into the seventh-largest U.S. steel company. Its minimills, which spin gleaming sheet steel out of scrapped cars and refrigerators, are efficient and profitable. Most of its 15 minimills are situated in small towns, where they employ and train people who never thought that they would make so much money. "Every manager wondering what it takes to compete in the twenty-first century needs to know the Nucor story," said Ann McLaughlin, the former U.S. secretary of labor. But there is another side of the Nucor story. Since 1980, its worker death rate has been the highest in the steel industry. Eleven employees have died as a result of accidents. Six more have died in accidents during construction of new plants. A review of court and safety documents and interviews with employees suggest that Nucor's work methods (and thus process design) and rush to maximize productivity may have a human cost. Nucor is a highly decentralized company that leaves safety up to the individual plant managers.

And the Environment

The chemical industry's record on the environment has been bad, and it still accounts for almost half of all toxic pollution produced in the United States. Things are changing, however, in part due to the legacy of Bhopal, India, where 3800 people died following the release of toxic gas at a Union Carbide Corporation subsidiary in 1984. Chemical companies are beginning to view waste as a measure of efficiency. The more unusable by-products a process creates, the less efficient it is. The Du Pont Company plant in Beaumont, Texas, used to spew out a staggering 110 million pounds of waste annually as byproducts of making plastics and paint. By adjusting its process design to use less of one raw material, it slashed the waste by two thirds. Du Pont's chairman and chief executive officer sees waste reduction as a way to achieve a competitive advantage.

Sources: "Nucor Steel's Sheen Is Marred by Deaths of Workers at Plants, "WallStreet Journal, May 10, 1991; "Chemical Firms Find That It Pays to Reduce Pollution it Source," Wall Street Journal, May 10, 1991.

Because the facets of process design are interrelated, a manager's choices concerning one may significantly affect choices concerning the others. Sales, as well as production costs, are affected by the manager's choices. For example, automation of GE's dishwasher plant in Louisville, Kentucky, which was an increase in capital intensity, helped increase the firm's market share from 32 to 40 percent. The stateof-the-art plant improved product quality and thus sales.

Capital Intensity

Whether designing a new process or redesigning an existing one, an operations manager must determine which tasks will be performed by human beings and which by machines. With the increased sophistication of modern computer hardware and software, process designers face an ever-widening range of choices, from operations requiring very little automation to those requiring task-specific equipment and very little human intervention. Automation is often heralded as a necessary ingredient to gaining competitive advantage. Actually there are both advantages and disadvantages: The automation decision requires careful examination.

Computers can significantly increase productivity. For example, Bailey Company, an independent Arby's franchisee based in Lakewood, Colorado, has installed computerized devices in its roast beef restaurants. Customers actually punch in their own orders on the devices, giving them more control over their orders and increasing employee efficiency amid a labor shortage. As the customer places the order, it appears on a similar screen in the kitchen area, eliminating the need for clerks to shout or walk orders back to the cooks. The system allows one clerk to handle two terminals for two lines of customers and has improved both service time (by about 20 seconds per order) and order accuracy. The system also encourages sales. For example, if a customer orders a sandwich and a salad but no soft drink, the screen illuminates a printed message suggesting a refreshing soda.

More capital intensity is not always best. A case in point is E.T. Wright's shoemaking plant, which a recent survey selected as one of the country's ten best-managed factories. The company still relies on skilled artisans and hand labor to make its arch-preserver shoes. Competitive priorities call for a unique product of high quality, even if a pair of shoes retails for more than $150. The firm has not been able to achieve these priorities with high capital intensity.

Some types of equipment can be acquired a piece at a time, allowing the user to try it out without making a large and risky initial capital investment. Examples of such equipment are new photocopy machines and stand-alone word processors and printers. However, many other technological choices involve large and costly systems – and a great deal more capital and risk.

Resource Flexibility

In Chapter 2 we discussed customization and volume flexibility as competitive priorities. Process design affects a firm's ability to achieve either one. And the choices that management makes concerning employees, facilities, and equipment determine the degree of resource flexibility. For example, when product plans call for short life cycles or high customization, equipment must be general purpose and employees need to perform a broad range of duties. Otherwise resource utilization will be too low for economical operation.

Until recently, the low production volumes associated with short life cycles and customization meant that a firm could not justify the investment dollars required to be capital intensive. The result was a strong inverse relationship between capital intensity and resource flexibility: When one was low the other was high. Figure 0.1 illustrates this relationship for two processes. Process 1 calls for inexpensive general-purpose equipment. It gets the job done but not at peak efficiency. Although fixed costs (F_1) are low, making it a less capital-intensive process, the variable unit cost (the slope of the total cost line) is high. Process 2 is more capital intensive: Although its fixed costs (F_2) are high, it is a more efficient process and therefore has a lower variable unit cost. Such efficiency often is possible only because the equipment is designed for a narrow range of products or tasks.

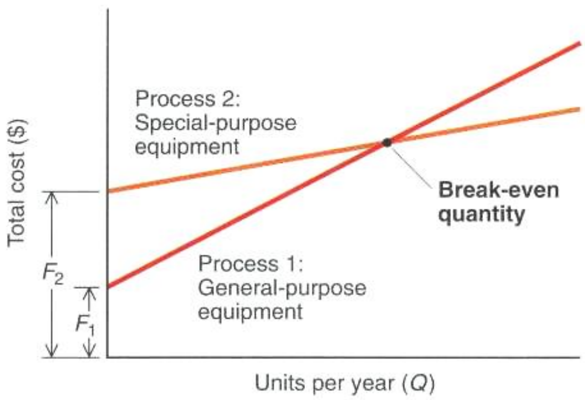


Figure 0.1 Relationship between Capital Intensity and Product Volume

The break-even quantity in Figure 0.1 is the quantity at which the total costs for the two alternatives are equal. At quantities beyond this point, the cost of process 1 exceeds that for process 2. The break-even quantity in Figure 0.1 is well to the right on the graph. Therefore, unless the firm expects to sell more than that amount (which is unlikely with high customization), the efficiency of process 2 is not warranted. For example, General Electric built a plant in Lynn, Massachusetts, to make parts for T700 jet engines at extremely low variable unit costs. The $52 million plant was highly automated (high fixed costs) and custom built to make these engines. Unfortunately, the Pentagon failed to order engines in the numbers anticipated, so the plant was running at only 60 percent of capacity—too low for an efficient operation. Also, the inflexibility of die process design makes it difficult to manufacture other products. The plant was built to make T700s – or similar-sized engines – and nothing else.

Exceptions to the inverse relationship between capital intensity and flexibility are beginning to emerge. As you will see in Chapter 6, technologies allowing certain types of flexible automation (such as robots) are now available. They are capital intensive but allow for more resource flexibility than in the past.

Resource flexibility also has important implications for the work force. Operations managers must decide whether to have a **flexible work force**. Members of a flexible work force are capable of doing many tasks, either at their own work stations or as they move from one work station to another. Such flexibility often comes at a cost, requiring greater skills and thus more training and education. Nevertheless, benefits can be large. We showed in one study that worker flexibility is one of the best ways to achieve reliable customer service and alleviate capacity bottlenecks (Ritzman, King, and Krajewski, 1984). We found resource flexibility to be particularly crucial to process-focused positioning strategy. Resource flexibility helps absorb the feast-or-famine workloads at individual operations that are caused by low-volume production, jumbled routings, and fluid scheduling.

Resource flexibility is practiced by manufacturers such as Westinghouse and Corning. Westinghouse's overhaul of its Sumter, South Carolina, plant allowed employees to perform a variety of tasks and resulted in increased productivity and capacity. Corning recently opened a plant in Blacksburg, Virginia, and trained its employees to have interchangeable skills. The workers must learn three skill modules—or families of skills—within two years to keep their jobs. A multiskilled work force is one reason why the Blacksburg Corning plant turned a $2 million profit in its first eight months of production, instead of losing $2.3 million as projected for the startup period. Training has been extensive, however. In the first year of production, 25 percent of all hours worked were devoted to training, at a cost of about $750,000.

Resource flexibility is also an issue in the service sector. Administrators of large urban hospitals must make decisions about staffing and degrees of specialization. Many hospitals use all registered nurses (RNs) instead of a mix of RNs, licensed vocational nurses (LVNs), and aides. Registered nurses have a higher education level and earn more than LVNs and aides, but they are more flexible and can perform all nursing tasks. Sometimes hospitals choose the opposite extreme (worker specialization) in an attempt to hold costs down. In Russia, for example, delicate eye surgery is performed in an "assembly line" consisting of patients on stretchers that move past five work stations. A surgeon at each station has three minutes to complete a specific portion of the operation before the patient moves on to the next surgeon. Obviously, these surgeons are highly specialized. Resource flexibility has been sacrificed, but great speed and economy are attained.

The type of work force required also depends on the need for volume flexibility. When conditions allow for a smooth, steady rate of output, the likely choice is a permanent work force that expects regular full-time employment. If the process is subject to hourly, daily, or seasonal peaks and valleys in demand, the use of part-time or temporary employees to supplement a smaller core of full-time employees may be the best solution. However, this approach may not be practical if knowledge and skill requirements are too high for a temporary worker to grasp quickly.

The Big Picture: Process Design at King Soopers Bakery

Now pause for a moment and look at The Big Picture illustration. We have literally lifted the roof of a multiproduct bakery, King Soopers, a division of Kroger Company, in Denver, Colorado, to show you process design at work in a real setting.

Notice that capital intensity and resource flexibility vary inversely, appropriate to the products made at King Soopers. To produce a relatively high volume of products (loaves of bread) efficiently, the bread line must be highly automated (high capital intensity), with very few people monitoring its operation. On the other hand, the line can produce only bread: It has low resource flexibility.

In stark contrast, the custom cake line produces very few cakes because it involves so much custom and hand work. Because several individual workers are required, capital intensity is low and resources are as flexible as they need to be to complete the unique custom orders.

The pastry line at King Soopers falls between the bread and cake lines in capital intensity and resource flexibility. The line is flexible enough to produce different kinds of pastries with little change in the line's resources.

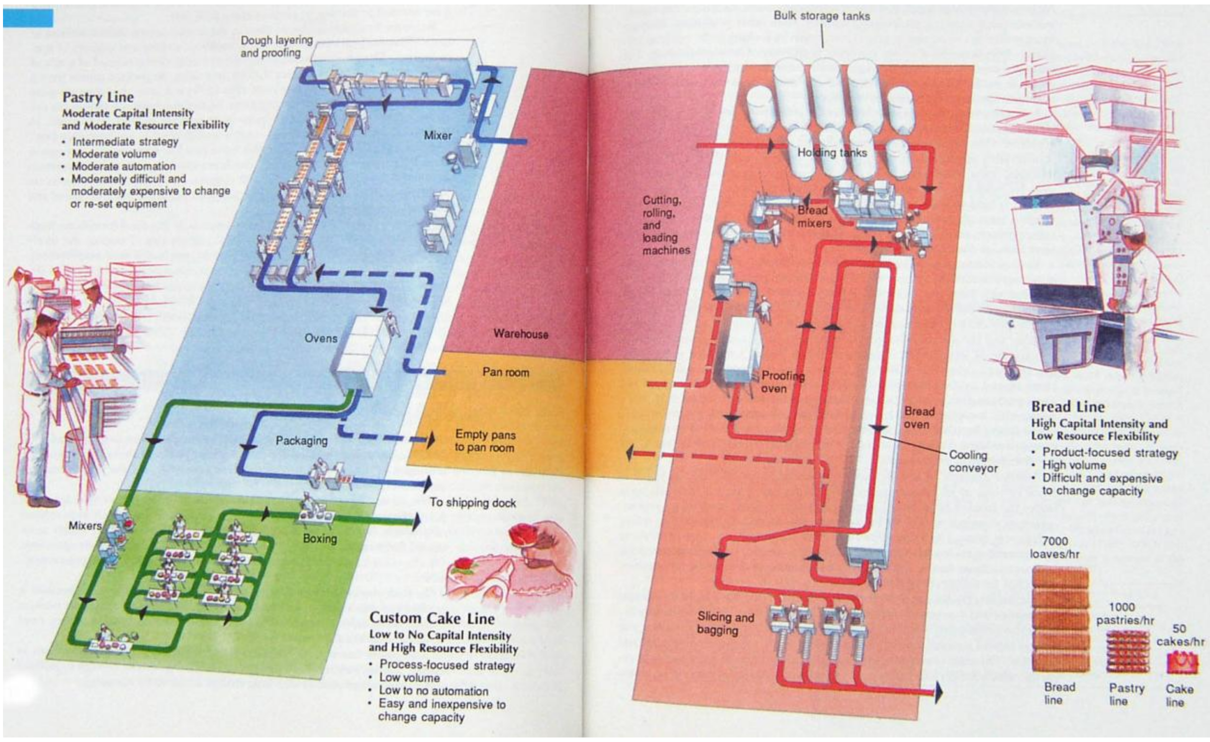


Figure 0.2 Process Flow at King Soopers Bakery

Vertical Integration

All businesses buy at least some inputs to their processes, such as raw materials, manufactured parts, or professional services, from other producers. Management makes decisions about vertical integration by looking at the entire supply chain from acquisition of raw materials to delivery of finished product. The more processes in the chain the organization controls, the more vertically integrated it is. As Managerial Practice 5.2 illustrates, firms may have different strategies for procuring necessary resources.

Extensive vertical integration is generally attractive when volumes are high and task specialization and high repeatability lead to greater efficiency. It is also attractive if the firm has the relevant skills and views the industry into which it is integrating as particularly important to its future success (Porter, 1990). For example, most small restaurants and food-service operators buy precooked eggs for salad bars and sandwiches from suppliers, rather than process their own. It is hard to match the efficiency of a supplier such as Atlantic Foods, where a team of six employees can peel 10,000 eggs in one shift. Similarly, a corner grocery store lacks the sales volume and resources to operate its own trout farm, as does Kroger Company.

Vertical integration can be in two directions. *Backward integration* represents movement toward the sources of raw materials and parts. (Managerial Practice 5.2 illustrates firms choosing more or less backward integration.) *Forward integration* means that the firm owns more channels of distribution, such as its own distribution centers (warehouses) and retail stores. Village Meats, a fresh-meat supplier and the dominant source of hamburger for Wendy's International, is an example of less forward integration. When Wendy's decided to have just one company deliver all of its fresh, frozen, and dry products, Village Meats chose to end its door-to-door deliveries. It had been delivering its meat and some produce directly to restaurants. Becoming the sole distributor to Wendy's restaurants, however, would have required the company to secure more warehouse space, handle frozen products, and purchase new trucks. The necessary investment was too much for its size. It still supplies Wendy's meat, but leaves the distribution to another firm.

Another example of less forward vertical integration is IBM's decision to allow versions of its minicomputer and mainframes to be marketed in Japan under the label of Mitsubishi Electric Corporation. IBM becomes an *original-equipment manufacturer (OEM)* for this part of its market and leaves the selling to Japanese firms. This move allows it to crack tough markets, such as Japanese government agencies. Mitsubishi

Electric, for example, is a big supplier to the Japanese defense forces and currently has more of a distinctive competence than IBM for selling computers in Japan.

Managerial Practice 0.2 . Choosing the right amount of vertical integration

More Integration

Kroger Company, the fourth-largest food retail chain in the United States on the basis of domestic sales, operates 1300 supermarkets and has considerable vertical integration. From 38 plants it manufactures products for sale under the Kroger label, including peanut butter, crackers, coffee, and many other dry groceries. Its operations also include 15 dairies, 11 bakeries, and a trout farm. Its extensive vertical integration lets it use cost as a competitive priority.

Dozens of U.S. corporations, frustrated with rising corporate health-care costs, are spurning the health-insurance industry to deal directly with health-care providers. They are betting that they can do it better and cheaper by applying the same management attention to health care that they do to their core businesses. For example, Baxter International, a big medical-supply company in Deer-field, Illinois, contracts directly with 350 doctors and several hospitals in a half-dozen locations. Baxter negotiates discounts and sets quality guidelines with health-care providers. Its staff regularly visit the providers to review data on trends in costs and procedures to make sure that the savings resulting from discounts aren't eroded by increased use of services. Employees submit their bills to Baxter, which subsidizes their health-care costs directly rather than rely on an insurance company to provide this service. In 1990 health-care costs rose only 12 percent among the 5000 employees who used the contract plan. This increase is much less than the 20 to 30 percent increases for Baxter's traditional plans offered through health-insurance companies. Such vertical integration requires purchasing power and a knowledgeable staff.

Less Integration

Japanese companies operating assembly plants in the United States have less vertical integration than do GM, Ford, and Chrysler because the former rely more on their suppliers. The Japanese firms do more outsourcing, which means that they buy more of the parts going into their automobiles from independent subcontractors. One big reason is that the suppliers pay lower wage rates. While the Japanese firms and the Big Three pay virtually identical wages for assembly workers in their own plants, independent subcontractors pay their workers perhaps $20 an hour less. Whereas the Japanese firms can take advantage of this differential by doing more outsourcing, the Big Three are prevented from doing so by UAW union resistance and so must do more part fabrication in-house.

For example, across the street from its Lake Orion assembly plant, GM operates a small plant that makes car seats. A forklift driver who hauls crates of cushions from the receiving docks to the line that assembles the seats earned $59,000 last year, albeit by working a lot of overtime. A worker at Johnson Controls, the biggest independent U.S. maker of car seats, earns half this amount. Not surprisingly, Johnson Controls is snapping up most of the seat-making business at the U.S. assembly plants of Nissan, Honda, and Toyota. The lower-cost seats help these Japanese companies build cars at a lower cost than the Big Three can.

LDDS Communications Inc., a long-distance carrier in Jackson, Mississippi, offers customized service to low-volume clients in 24 states. Whereas big carriers tend to sell uniform products to small businesses, LDDS tries to tailor its service to each customer's calling patterns to cut costs. LDDS is too small for much vertical integration: It owns its own switches but can't afford to build its own transmission network. Instead it leases transmission facilities from AT&T, MCI, and other larger carriers. This strategy has worked well in the past because the larger carriers cut leasing prices to LDDS to use up excess capacity. Now price cuts are abating, making the big carriers an ever-present threat to small carriers, such as LDDS, which collectively control little more than 1 percent of the total long-distance market.

(Sources: "Kroger Chief Expects Asset Sale to Reap $333 Million for Bid to Stay Independent," Wall Street Journal, September 27, 1988; "Firms Perform Own Bypass Operations, Purchasing Health Care from the Source," Wall Street Journal, August 19, 1991; "UAW and Big Three Face Mutual Mistrust as Auto Talks Heat Up," Wall Street Journal, August 29, 1990; "LDDS Communications Wins Big by Thinking Small," Wall Street Journal, July 26, 1991.)

Vertical integration can reduce resource flexibility in that a large investment in facilities and equipment may not be easy to reverse. When customers became less enthusiastic about house brands and generic (no-brand) products and turned toward national brands, Kroger found itself with idle equipment and facilities. The shift in consumer preferences created excess manufacturing capacity, which Kroger had to find a way to utilize. It did so by making ice cream and frozen pizza dough for its competitors, which in turn sold the products under their own labels. About 20 percent of the sales from its plants are now to companies outside Kroger. It also has sold some of its plants. While these may be ideal solutions, extensive vertical integration limited Kroger's resource flexibility and range of acceptable business opportunities.

Hollow corporations use a converse strategy to that of Kroger: gaining flexibility but taking a different risk. A hollow corporation is a small central firm that relies on other firms for most of its production—and for many of its other functions—on a contract basis. It is sometimes called a *network company* because its few employees spend most of their time on the telephone coordinating suppliers. Lewis Galoob Toys, which features trendy toys, is a good example. So are Emerson Radio (consumer electronics) and Liz Claiborne (apparel). Hollow corporations can move in and out of markets, riding the waves of fashion and technology. They are vulnerable to new competition, however, because the investment barriers to enter their businesses are low: Their suppliers can integrate forward or their customers can integrate backward. A hollow corporation's risk of losing its business to suppliers or customers increases as product volumes increase and product life cycles lengthen. For example, Conner Peripherals has been very successful since entering the hard disk drive industry in 1986. Because product life cycles are so short, often measured in months, it lets outside suppliers manufacture the parts it designs and therefore avoids investing in factories that become obsolete as technology changes. If life cycles were longer, then one of its big customers, such as Compaq Computer Corporation, might decide to make the computer drives itself and bypass Conner entirely.

Application 0.1 Break-even analysis for Make-or-Buy Decisions

The manager of a fast-food restaurant featuring hamburgers is adding salads to the menu. There are two options, and the price to the customer will be the same for each one. The "make" option is to install a salad bar stocked with vegetables, fruits, and toppings and let the customer assemble the salad. The salad bar would have to be leased and a part-time employee hired. The manager estimates the fixed cost at $12,000 and variable costs totaling $1.50 per salad. The "buy" option is to have preassembled salads available for sale. They would be purchased from a local supplier at $2.00 per salad. With preassembled salads it would be necessary to install and operate additional refrigeration, with a fixed cost of $2,400. The manager expects to sell 25,000 salads per year. What is the break-even quantity?

Solution:

Set the fixed cost plus the variable cost (F + cQ) for the buy option equal to the equivalent costs for the make option, then solve for Q:

$2,400 + 2.0Q = $12,000 + $1.5Q $0.5Q = $9,600

Q = 19,200 salads

The break-even quantity is 19,200 salads. Since the 25,000-salad sales forecast exceeds this amount, the make option is preferred. Only if the restaurant expected to sell fewer than 19,200 salads would the buy option be best.

Make or Buy.

Backward integration is often referred to as the *make-or-buy decision.* The operations manager must study all the costs and advantages of each approach. Break-even analysis is a good starting point. However, its application differs from that for product and service planning (see Chapter 2) because it is assumed that the decision doesn't affect revenues. Rather than find the quantity where total costs equal total revenues, the analyst finds the quantity for which the total costs for two alternatives are equal. For the make-or-buy decision, this is the quantity for which the total "make" cost equals the total "buy" cost. The buy option may or may not have a fixed cost. To find the break-even quantity, equalize the two cost functions and solve for *Q,* as follows:

$$F_b + c_b Q = F_m + c_m Q$$

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

where F_b is the fixed cost (per year) of the buy option, F_m is the fixed cost of the make option, c_b is the variable cost (per unit) of the buy option, and c_m is the variable cost of the make option.

The make option would never be considered, ignoring qualitative factors for the moment, unless its variable cost were lower than that of the buy option. The reason is that fixed costs for making the product or service are typically higher than for buying. Under these circumstances, the buy option is best if production volumes are less than the break-even quantity. Beyond that quantity, the make option becomes best.

Equally important are qualitative factors. The customers of the restaurant in Application 5.1, for example, might be willing to pay more for a salad that they can make to their own tastes (that is, more customization). Or perhaps a preassembled salad doesn't fit the customers' image of the restaurant. Although some "make" decisions require sizable capital investments, they may take better advantage of the firm's human resources, equipment, and space.

Own or Lease.

When a firm decides on more vertical integration, it must also decide whether to own or to lease the necessary facilities and equipment. The lease option is often favored for items affected by fairly rapid changes in technology, items that require frequent servicing, or items for which industry practices have made leasing the norm, as in the photocopier industry. Leasing is also common when a firm has a short-term need for equipment. For example, in the construction industry, where projects usually take months or years to complete, heavy equipment is often leased only as needed.

Many firms lease payroll, security, cleaning, and other types of services, rather than employ personnel and use their own resources to provide these services. Frequently, an organization can hire a firm with the desired expertise and obtain higher-quality service at lower cost than it could from a staff of its own.

Customer Involvement

At Wendy's SuperBar customers assemble their own salads and make selections from Mexican and Italian dishes. Bucking a trend away from salad bars, Wendy's gets 25 percent of its sales from food bars.

The fourth facet of process design is the extent to which customers interact with the process. In many service industries, customer contact is crucial. Customers are involved in terms of self-service, product selection, and time and location, as at Wendy's SuperBar.

Self-Service. To save money, some customers prefer to do part of the process formerly performed by the manufacturer or dealer. Self-service is the process design choice of many retailers, particularly when price is a competitive priority. Some product-focused manufacturers also use self-service to advantage. Their customers become the final assemblers of toys, bicycles, furniture, and other products. Production, shipping, and inventory costs frequently are lower, as are losses from damage.

Product Selection. A business that competes on customization frequently allows customers to come up with their own product specifications or even become involved in designing the product. For example, salad bar customers have more control over portions and ingredients. Another good example of customer involvement is in custom-designed and -built homes; the customer is heavily involved in the design process and inspects the work in process at various times. Furthermore, customer involvement is not likely to end even when the owner occupies the house, because most builders guarantee their work for some extended time period.

Time and Location. For industries in which service cannot occur without the customer's presence, time and location issues affect the process design. If the service is delivered to the customer, client, or patient by appointment, decisions involving the location of such meetings become part of process design. Will customers be served only on the supplier's premises, will the supplier's employees go to the customers' premises, or will the service be provided at yet a third location? Operators of emergency ambulance services cannot provide service without a patient. They cannot predict when the next call for service will come in or where the ambulance will have to go, so they must design their response processes accordingly. On the other hand, in their role as independent auditors, certified public accountants frequently work on their clients' premises, a situation in which both the time and place are likely to be known well in advance.

High customer involvement processes tend to be less capital intensive and more resource flexible than do low customer involvement processes. These conditions are particularly relevant when there is a need for full service, customized orders, unpredictable demands, and service provision at customer locations. Exceptions, such as telephone exchanges, vending machines, and automatic bank tellers, can be found, mainly because these processes require minimal personalized attention.

Relationships Between Facets

We have already identified several relationships among the four facets of process design. An underlying variable that creates these relationships is volume. High volume comes from large product or service demands, significant work content per unit made or served, standardization of parts, and task specialization. Figure 0.3 shows how the process design facets and positioning strategy are inextricably tied to volume. The solid vertical lines show the link between volume and positioning strategy, and the dashed horizontal lines show the subsequent link between positioning strategy and process design. For example, when volume is low (volume A,) a process focus is the likely choice, whereby the firm is likely to have more customer involvement and opt for more resource flexibility, less capital intensity, and less vertical integration (process design choices A_2). A product-focused facility (volume B,) opts for the opposite ends of the continuum (choices B_2). The high volumes of a product focus, which typically mean less customer involvement, justify the large fixed cost of an efficient capital-intensive operation. They also reduce the need for resource flexibility and create more opportunities for vertical integration. Kroger's large volumes encouraged it to have extensive vertical integration, while LDDS's low volumes led it to rely on others to provide the transmission network.

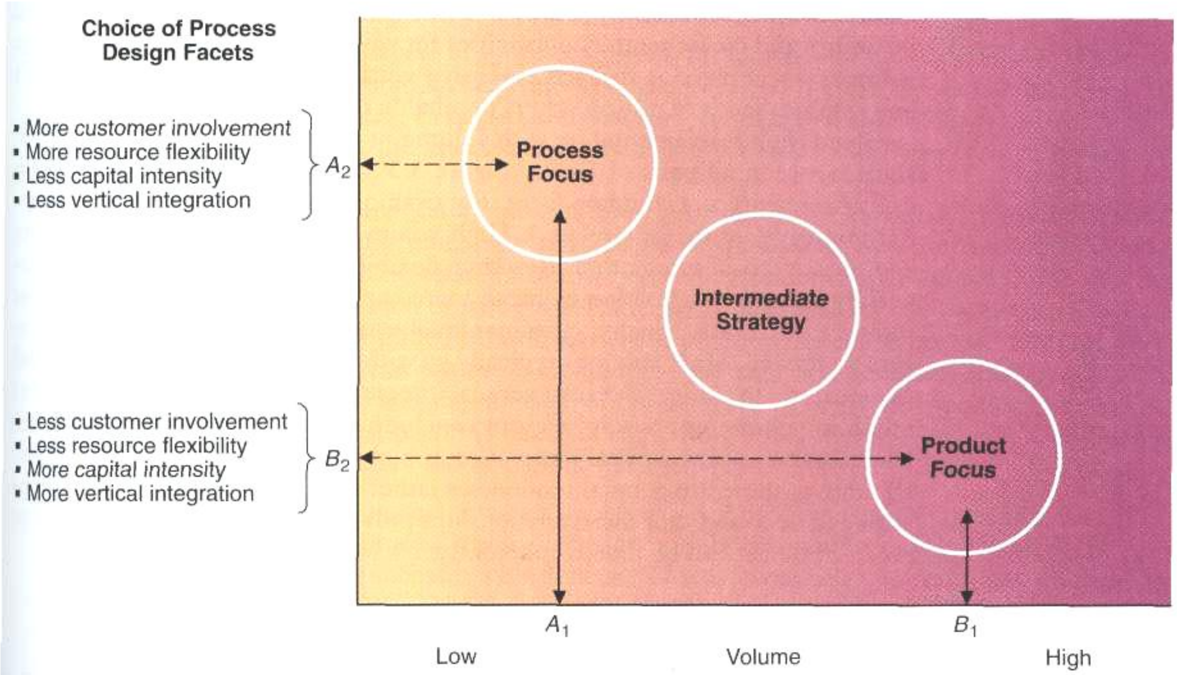


Figure 0.3 Volume, Positioning Strategy, and Process Design Facets

Given their fundamental tie with volume, it is possible to infer the relationships between all pairs of facets. Figure 0.4 shows three such pairings, with capital intensity as a common facet. For example, vertical integration and capital intensity are directly related: High volumes mean more capital intensity and more vertical integration. Resource flexibility and capital intensity are inversely related: High volumes mean more capital intensity and less need for resource flexibility. Finally, customer involvement and capital intensity are inversely related: High volumes typically go with less customer involvement and more capital intensity. Because vertical integration and customer involvement relate to volume oppositely, we can conclude that they are also inversely related; that is, when vertical integration is high, customer involvement is low. Of course, these are general tendencies rather than unbreakable laws. Exceptions can be found, but these relationships provide a way of understanding how process choices can be linked coherently.

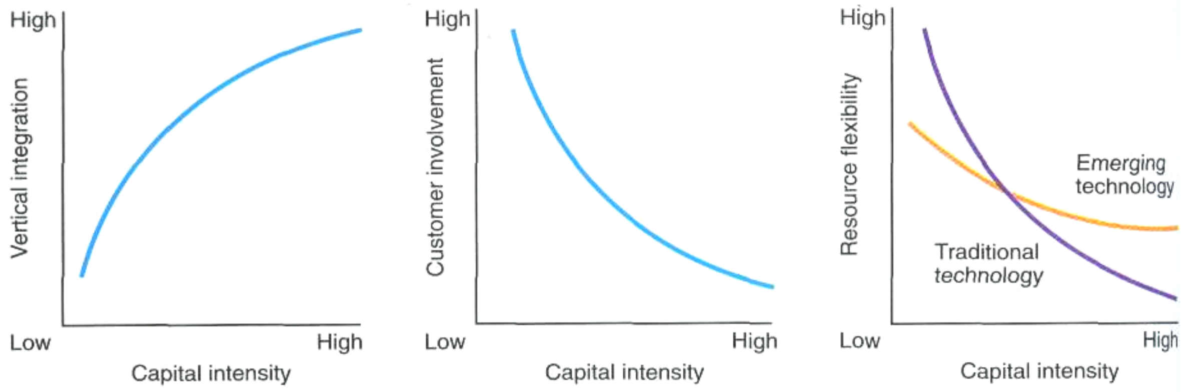


Figure 0.4 Relationships Between Facets

Capital Budgeting

Capital budgeting is a method to allocate scarce funds among competing investment alternatives. Ideas for improving a process, including a change in one of the process design facets, often call for capital investment in facilities and equipment. For example, further vertical integration by a firm invariably requires more equipment and perhaps a new facility. As most of a firm's assets are usually committed to operations, many ideas originate there for capital expenditures and proposals for their inclusion in the firm's capital budget.

Operations managers are constantly looking for ways to encourage innovative ideas for improving productivity. At the same time, they must screen out ideas that don't fit with established operations strategy or generate enough benefits. Benefits can be labor savings, materials cost reduction, less scrap, better quality, lower inventory, better customer service, or higher revenues. Benefits can also be more qualitative, such as expanded opportunities for future products resulting from greater resource flexibility. The operations manager must estimate the costs, benefits, and risks involved in the proposed change. These estimates are then analyzed by means of one or more capital budgeting techniques, such as net present value, payback, or internal rate of return. A brief review of these techniques is found in Supplement 1.

The final decisions in capital budgeting are made by top management—or even the board of directors when a major capital investment is proposed. They make sure that very large investments in equipment and facilities are in line with corporate strategies, particularly with respect to product plans and competitive priorities.

PROCESS ANALYSIS

The four facets of process design represent broad, strategic issues. There is another, more tactical side to process design: the careful, detailed analysis of each process. Process analysis, sometimes called *methods study* or *work simplification*, is the systematic study of the activities and flows of each process to improve it.

In this section we present three basic techniques for analyzing activities and flows within processes: flow diagrams, process charts, and multiple activity charts. These techniques can be used systematically to question the process itself and each of its details. The operations manager can highlight tasks that can be simplified or indicate where productivity can otherwise be improved. Managers can use these techniques to design new processes and redesign existing ones and should use them periodically to study all operations. However, the greatest payoff is likely to come from applying them to operations having one or more of the following characteristics:

- The process involves disagreeable or dangerous working conditions.
- The process results in pollution or large amounts of waste materials.
- The process is a bottleneck. That is, work piles up waiting to go through this process, and people or machines are idle while waiting for the output of the process.
- The process consumes a great amount of time.
- The process requires a great deal of physical movement.

All three analytic techniques involve breaking a process into detailed components. To do this, the manager should ask six questions:

1. *What* is being done?

2. *When* is it being done?
3. *Who* is doing it?
4. *Where* is it being done?
5. *How long* does it take?
6. *How* is it being done?

Answers to these questions are challenged by asking still another series of questions. Why? Why is the process even being done? Why is it being done where it is being done? Why is it being done when it is being done? Such questioning often can lead to creative answers that can cause a breakthrough in process design. Work elements can be streamlined, whole processes eliminated entirely, raw material usage cut, or jobs made safer. Most facilities can trim labor costs by eliminating unnecessary functions – parts inspection, warehousing, materials handling, and redundant supervision, among others – and reorganizing the production process. For example, Eaton Corporation rearranged its plant in Marshall, Michigan, so that a rough forging placed on a conveyor travels automatically from machine to machine until it emerges as a polished gear for a truck differential. Computerized measuring machines, instead of human inspectors, ensure that automated turning centers cut gears to a precise size. Such changes came from a critical analysis of each process.

Flow Diagrams

When an operation involves considerable movement of materials or people, a flow diagram is a useful analytical tool. A flow diagram traces the flows of people, equipment, or materials through a process. To make a flow diagram, the analyst first makes a rough sketch of the area in which the process is performed. On a grid (graph paper or other paper marked off in squares) the analyst plots the path followed by the person, material, or equipment, using arrows to indicate the direction of movement, or the direction of flow.

Figure 0.5 shows a flow diagram for a car wash facility, illustrating the flows of cars and customers. Cars enter one of two lines from the street and alternate in forming a single line that rounds a sharp corner into the washing bay. Just before a car enters the bay, the customer exits the car and walks through a separate door and hallway to the office and pays for the service. The car proceeds through the washing bay, and the customer exits through the hallway and out a second door to rejoin the car after it is rolled to an open area and wiped down. The customer then gets back into the car and drives away. The facility used to have only one waiting line, but during peak periods, the line of cars would extend back into the street, blocking traffic. The owner used a flow diagram to determine that the second waiting line could be added without changing the flow of the other operations. (Queuing and simulation analysis, described in Supplements 4 and 5, are more extensive methods to study waiting lines.)

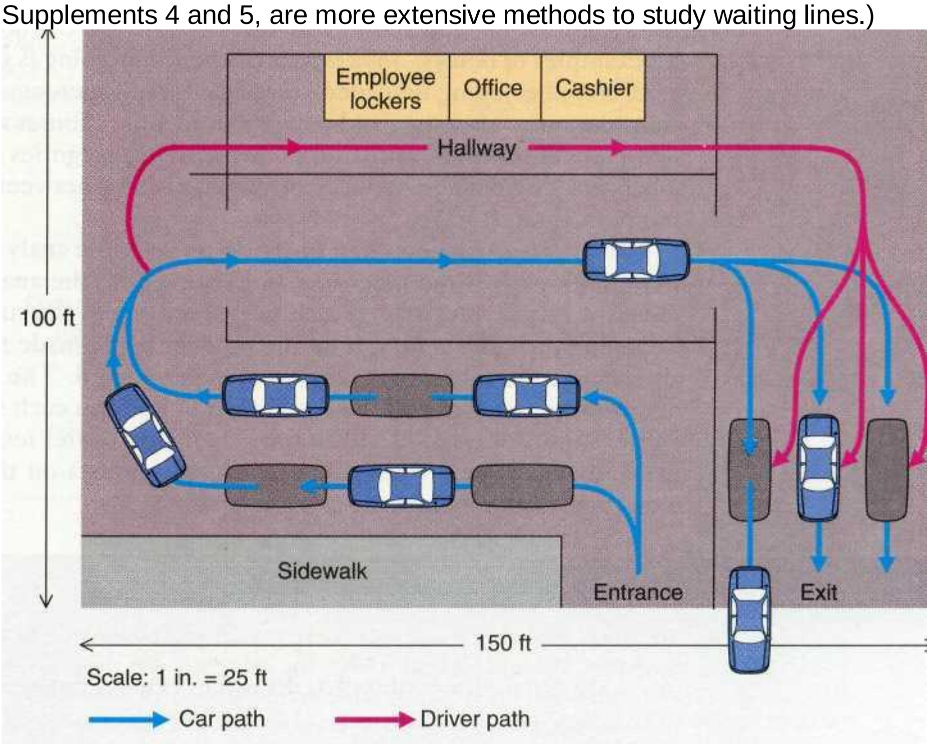


Figure 0.5. Flow diagram for a car wash facility

Process Charts

A **process chart** is an organized way of recording all the activities performed by a person, by a machine, at a work station, or on materials. For our purposes we group these activities into five categories:

- operation
- transportation
- inspection
- delay
- storage

An *operation* is productive work that changes, creates, or adds something. Examples are mixing tar, stone, and sand to make asphalt; drilling a hole; and serving a customer at a store. *Transportation* (sometimes called materials handling) is the movement of the study's subject from one place to another. The subject can be a person, a material, a tool, or a piece of equipment. Examples of transportation are a customer walking from one end of a counter to another, a crane hoisting a steel beam to a location, and a conveyor carrying a partially completed product from one work station to the next. An *inspection* checks or verifies something but does not change it. Checking for blemishes on a surface, weighing a product, and taking a temperature reading are examples of inspections. A *delay* occurs when the subject is held up awaiting further action. Time spent waiting for materials or equipment, time for cleanup, and time that workers, machines, or work stations are idle because there is nothing for them to do are examples of delays. *Storage* occurs when something is put away until a later time. Supplies being unloaded and placed in a storeroom as inventory, equipment put away after use, and papers put in a file cabinet are examples of storage. Depending on the situation, other activity categories can be used, such as subcontracting/outside services or distinguishing between temporary storage and permanent storage.

To complete a process chart for a new process, the analyst must identify each step performed. If the process is an existing one, the analyst can actually observe the steps, categorizing each step according to the subject being studied. Changing the subject (say, from the product being made to the worker) might also change the category to which a step is assigned. The analyst then records the distance traveled and the time taken to perform each step. (See Chapter 7 on the various ways to establish time standards.) After recording all the activities and steps, the analyst calculates summary data on the number of steps, total times, and total distance.

Application 0.2 Completing a Process Chart

You are to analyze the process of baking a batch of brownies. The subject of the study is the baker. The process begins when the baker removes the preassembled brownie mix and ends when the large pan is placed in the oven for baking. Raw materials (the brownie mix, water, and eggs) and equipment and container (bowl, mixer, measuring container, and pan) must be assembled. The ingredients must be measured, mixed, poured in a pan, and placed in the oven.

Solution

Figure 0.6 shows the completed process chart. The process is broken into 26 steps. A summary of the times and distances traveled is shown in the upper-right hand corner of the process chart. The times add up to 27.2 minutes, and the baker travels a total of 430 feet.

After the process is charted, the analyst estimates the annual cost of the entire process. The annual cost becomes a benchmark against which other methods for performing the process can be evaluated. Annual labor cost, for example, can be estimated by finding the product of (1) time in hours to perform the process each time, (2) variable cost per hour, (3) number of times the process is performed each week, and (4) number of weeks per year in which the process is performed.

Process: MAKING ONE BATCH OF BROWNIES
Subject charted: BAKER
Beginning: REMOVE BROWNIE MIX FROM BIN
Ending: PLACE PAN IN OVEN

Summary

Activity		Number of Steps	Time	Distance
Operation	●	15	18.0	–
Transport	➡	9	9.0	430
Inspect	■	2	0.2	–
Delay	◗	0	–	–
Store	▼	0	–	–

Step No.	Time (min)	Distance (ft)	●	➡	■	◗	▼	Step Description
1	1.3		X					REMOVE PREASSEMBLED MIX FROM BIN
2	0.2		X					PLACE MIX ON COUNTER
3	1.2	60		X				WALK TO CABINET
4	0.4		X					REMOVE BOWL AND MIXER
5	1.2	60		X				RETURN THE BOWL AND MIXER TO COUNTER
6	0.2		X					PLACE BOWL AND MIXER ON COUNTER
7	1.3		X					OPEN BAG OF MIX AND DUMP INTO BOWL
8	1.2	60		X				WALK TO CABINET
9	0.3		X					REMOVE PAN AND MEASURING CONTAINER
10	1.2	60		X				RETURN WITH THEM TO COUNTER
11	0.2		X					PLACE THEM ON COUNTER
12	0.6	30		X				WALK TO REFRIGERATOR
13	0.8		X					REMOVE EGGS FROM REFRIGERATOR
14	0.6	30		X				WALK BACK TO COUNTER
15	0.1		X					PLACE EGGS ON COUNTER
16	3.1		X					BREAK EGGS INTO BROWNIE MIX; DISCARD SHELLS
17	2.2		X					USE MIXER TO STIR EGGS AND BROWNIE MIX
18	0.9	40		X				PICK UP MEASURING CONTAINER; WALK TO SINK
19	1.4		X					FILL MEASURING CONTAINER WITH WATER
20	0.8	40		X				WALK BACK TO COUNTER
21	0.3		X					POUR WATER INTO BROWNIE MIX
22	4.3		X					USE MIXER TO STIR INGREDIENTS IN BOWL
23	0.1				X			INSPECT MIXTURE IN BOWL
24	1.9		X					POUR MIXTURE INTO PAN
25	0.1				X			INSPECT MIXTURE IN PAN
26	1.3	50		X				PICK UP PAN; WALK TO OVEN; PLACE PAN IN OVEN

Figure 0.6 Process Chart for Making Brownies at a Bakery

Application 0.3 Computing the Annual Labor Costs

The baker earns $17 per hour (including fringe benefits) and makes 12 batches per week. What is the annual labor cost?

Solution

$$AnnualLaborCosts = \frac{27.2\,\text{min}}{60\,\text{min}/\,hr}(\$17/hr)(12/wk)(52wk/yr) = \$4809$$

The calculations convert minutes to hours and then multiply this figure by the hourly rate and the number of baker hours per year needed for the process. Adding in the cost of materials would yield a sizable variable cost, and brownies are but one of many products made at the bakery.

Next comes the creative part of process analysis. The analyst now asks the what, when, who, where, how long, and how questions, challenging each of the steps of the process charted. The summary of the process chart indicates which activities take the most time. To make a process more efficient, the analyst should question each delay and then analyze the operation, transport, inspection, and storage activities to see whether they can be combined, rearranged, or eliminated. There is always a better way, but someone must think of it. Improvements in productivity can be significant.

Application 0.4 Improving the Process

What improvement can you make in the process in Figure 0.6?

Your analysis should verify the following two ideas for improvement. You may also be able to come up with others.

1. **Combine the trips for equipment**. The baker walks to the cabinet twice to get tools. This is inefficient because the tools aren't heavy or large enough to require two trips. Even if they were unwieldy, he could use a cart. Combining steps 3—5 and 8-10 saves time, as the baker gathers all the tools at once and eliminates 120 feet of travel.
2. **Eliminate the first mixing**. Steps 16,17,21, and 22 can be rearranged to add the eggs and water to the brownie mix before mixing. This cuts out another step.

Multiple Activity Charts

A process chart describes the work being done by or on just one subject. However, simultaneously tracking multiple subjects may be more revealing. A **multiple activity chart,** sometimes called a *man-machine chart,* is a record of the activities performed by or on several subjects over a given time period. The first step in preparing these charts is to determine which process to study. The analyst divides a sheet of paper into columns, with one for each person, material, or work station. The analyst next observes the process and establishes a time standard for each activity (see Chapter 7). Finally, the analyst charts the time required to perform each activity, using vertical bars having lengths that represent these times.

Application 0.5 Completing a Multiple Activity Chart

Dr. Wilson, an orthodontist with a large practice, sees patients biweekly for adjustment of their braces. The receptionist seats the patient in one of four chairs, and Dr. Wilson then checks the patient. After making his check and washing up, which takes about a minute, one of the two orthodontic technicians adjusts the patient's braces. The adjustment procedure takes the technicians about 8 minutes per patient. After the braces are adjusted, Dr. Wilson again checks the patient, makes any necessary final adjustment, and washes up again. This final step takes about 2 minutes. Dr. Wilson's objective is to get them in and out of the chair in 20 minutes or less. The technicians take about one minute between patients to wash their hands, and each technician is allowed to take a 5-minute break at the end of each hour.

Prepare a multiple activity chart for the first hour of a day, with columns for the orthodontist, two technicians, and four chairs. Because we are interested in only one of the receptionist's activities—seating the patients—you do not need an extra column for the receptionist. Let technician 1 work on patients in chairs A and B, and technician 2 work on patients in chairs C and D. Assume that it is a busy morning and that patients are available as soon as they can be handled.

Solution

Figure 0.7 shows the completed chart. Technician utilization (the time they are occupied divided by the period of time being studied) is a very high 88 percent. Dr. Wilson's utilization is much lower, however. He is occupied only 36 minutes of the hour, for a utilization rate of 36/60 = 60 percent. The chart also indicates the amount of time that each chair is unoccupied or is occupied by a patient waiting for the next step in the process. A patient in chair A had to spend only 2 minutes waiting, and the chair was unoccupied for 22 minutes of the hour (shown as idle time). Chair D was empty for only 15 minutes, and patients had to wait 9 minutes. As this waiting time was spread over three patients, for 3 minutes each, it was probably acceptable to them.

The next step is to find ways to improve the process. Analyzing the multiple activity chart can uncover ways to divide work among employees, reduce time required for certain activities, or rearrange activities to shorten a job's overall time. It helps managers decide how to utilize people, work stations, or machines more effectively. Managers frequently use multiple activity charts to find ways to minimize idle time. The result can be significant productivity improvements. Such is the case for dentistry, which is a much different business than it used to be. The dental profession stands out in the health-care industry as a leader in productivity improvement. These substantial gains are being studied carefully by the rest of the health-care industry

Application 0.6 Improving the Multiple Activity Process

Many patients are referred to Dr. Wilson, and he would like to expand his practice without devoting more hours to routine brace adjustments. He is thinking of adding two more chairs and hiring one more technician. He would continue to spend one minute with the patients before the technicians work on them and about two minutes with them after the technicians have finished. How many more patients can he see, and what will be the utilizations and patient watt times, with the expansion?

Solution

The new chart is shown in Figure 0.7. The orthodontist now has as little unoccupied time as the technicians. All are busy for 53 of the 60 minutes, for utilization ratios of 88 percent. Even though almost every patient has to wait before and after seeing the technician, no patient's total time in the chair exceeds 20 minutes, so that goal can be met. It appears that Dr. Wilson can add two chairs and an additional technician to his staff and see 18 patients every hour instead of 12, but he and his technicians would be very busy.

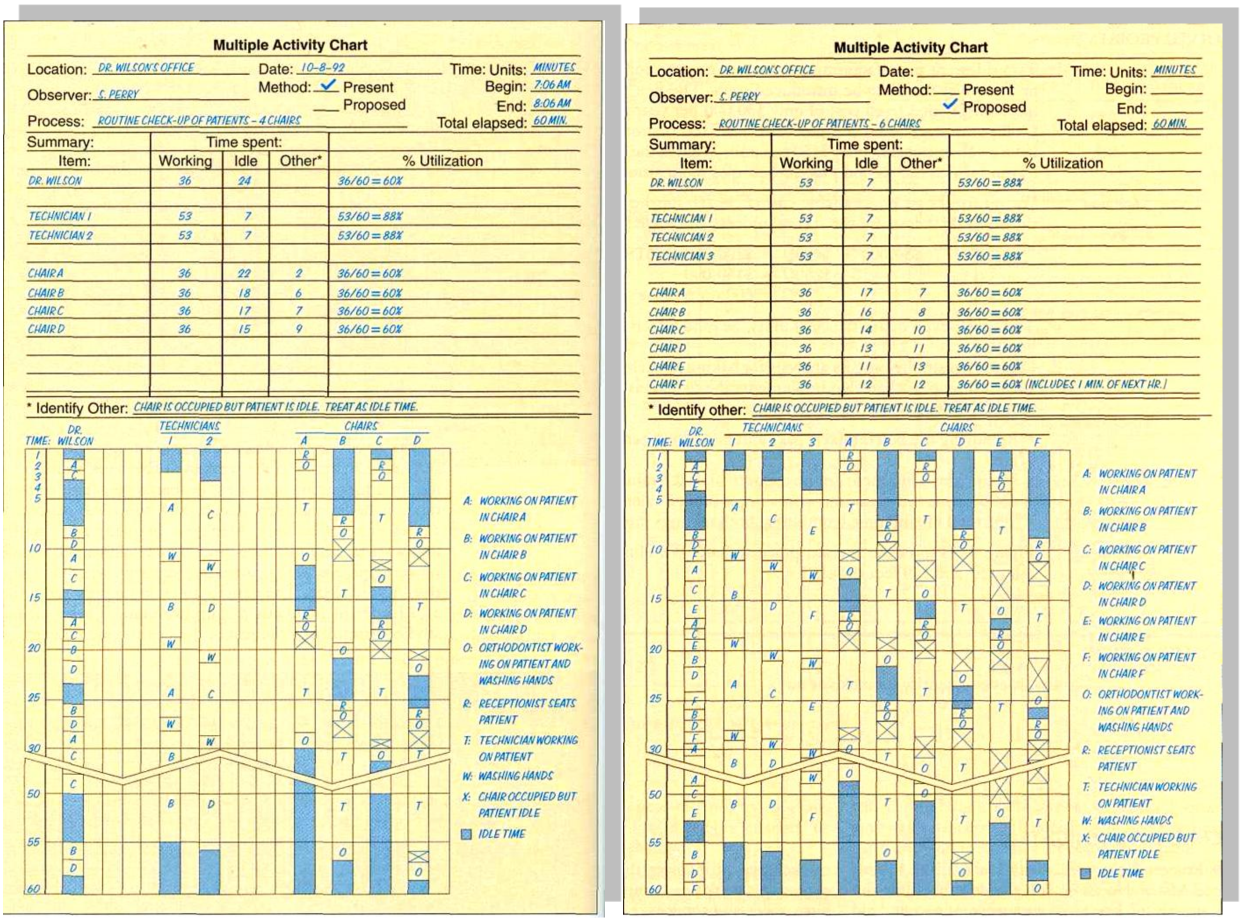


Figure 0.7 Multiple Activity Chart for Orthodontist: 4 and 6 chairs

SOLVED PROBLEMS

1. Two different manufacturing processes are being considered for making a new product that is to be introduced soon. The first process is less capital intensive, with a fixed cost of only $50,000 per year and a variable cost of $400 per unit. The second process has a fixed cost of $200,000 but would have a variable cost of only $150 per unit. What is the break-even quantity, beyond which the second process becomes more attractive than the first?

Solution

We set fixed cost plus variable cost *(F + cQ)* for the first process equal to the equivalent costs for the second process and solve for *Q:*

$50,000 + $4000 = $200,000 + $1500 $25O£? = $150,000 *Q* = 600 units

The break-even quantity is 600 units, beyond which the second process is better.

2. Consider again the process analysis for baking a batch of brownies. Prepare a revised process chart that implements the two ideas proposed in Application 5.4. The only new information is:

- Removing the bowl, mixer, pan, and measuring container takes 0.5 minute.
- Placing the equipment on the counter takes 0.3 minute, up from 0.2 minute because the measuring container is brought along on the trip.
- The total mixing time (combining both mixings into one) is 5.0 minutes.

Solution

Figure 0.8 shows the revised process chart. We eliminate five steps, 4.5

minutes, and 120 feet traveled.

Process: MAKING ONE BATCH OF BROWNIES
Subject charted: BAKER
Beginning: REMOVE BROWNIE MIX FROM BIN
Ending: REMOVE BROWNIES FROM OVEN

Summary

Activity	Number of Steps	Time	Distance
Operation ●	12	15.9	–
Transport ➡	7	6.6	310
Inspect ■	2	0.2	–
Delay D	0	–	–
Store ▼	0	–	–

Step No.	Time (min)	Distance (ft)	●	➡	■	D	▼	Step Description
1	1.3		X					REMOVE PREASSEMBLED MIX FROM BIN
2	0.2		X					PLACE MIX ON COUNTER
3	1.2	60		X				WALK TO CABINET
4	0.5		X					REMOVE BOWL, MIXER, PAN, AND MEASURING CONTAINER
5	1.2	60		X				RETURN TO COUNTER WITH EQUIPMENT
6	0.3		X					PLACE EQUIPMENT ON COUNTER
7	1.3		X					OPEN BAG OF MIX AND DUMP INTO BOWL
8	0.6	30		X				WALK TO REFRIGERATOR
9	0.8		X					REMOVE EGGS FROM REFRIGERATOR
10	0.6	30		X				WALK BACK TO COUNTER
11	0.1		X					PLACE EGGS ON COUNTER
12	0.9	40		X				PICK UP MEASURING CONTAINER; WALK TO SINK
13	1.4		X					FILL MEASURING CONTAINER WITH WATER
14	0.8	40		X				WALK BACK TO COUNTER
15	0.3		X					POUR WATER INTO BROWNIE MIX
16	2.8		X					BREAK EGGS INTO BROWNIE MIX; DISCARD SHELLS
17	5.0		X					USE MIXER TO STIR INGREDIENTS IN BOWL
18	0.1				X			INSPECT MIXTURE IN BOWL
19	1.9		X					POUR MIXTURE INTO PAN
20	0.1				X			INSPECT MIXTURE IN PAN
21	1.3	50		X				PICK UP PAN; WALK TO OVEN; PLACE PAN IN OVEN

Figure 0.8 Process Chart After Improvement

FORMULA REVIEW

Break-even quantity for make or buy:

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

CHAPTER HIGHLIGHTS

✓ Process design deals with *how* to make a product. Many choices must be made concerning the best mix of human resources, equipment, and materials.

- ✓ Process design is of strategic importance and is closely linked to the productivity levels a firm
- ✓ can achieve. It involves the selection of inputs, operations, work flows, and methods used to produce goods and services.
- ✓ Process design decisions are made when a new product is to be offered or an existing product modified, demand levels change, current performance is inadequate, new technology is available, costs or availability of inputs change, or competitive priorities change.
- ✓ Four facets of process design are capital intensity, resource flexibility, vertical integration, and customer involvement. *Capital intensity* concerns the mix of capital equipment and human skills in a process. *Resource flexibility* reflects the degree to which equipment is general purpose and individuals can handle a wide variety of work. *Vertical integration* concerns the decisions to make or buy parts and services. Such decisions are made by looking at the entire chain of supply from acquisition of raw materials to delivery of the finished product to the consumer and then determining which processes the firm itself wants to perform. *Customer involvement* is the extent to which customers are allowed to interact with the production process. Self-service, product selection, and the timing and location of the interaction must all be considered.
- ✓ Relationships among these facets suggest how process choices can be linked coherently. For example, higher capital intensity is usually associated with lower resource flexibility, higher vertical integration, and lower customer involvement. The variable underlying these relationships is volume.
- ✓ Process design choices often require investment in new facilities or equipment. Operations managers must assess benefits and costs of each investment proposed. After the necessary estimates have been made, break-even analysis or net present value techniques can be applied. • Three techniques for analyzing process activities and flows are flow diagrams, process charts, and multiple activity charts. All are organized ways of studying the details of a process to improve it by designing or redesigning it.

KEY TERMS

- capital budgeting
- capital intensity
- customer involvement
- flexible work force
- flow diagram
- hollow corporation
- multiple activity chart
- process analysis
- process chart
- process design
- resource flexibility
- vertical integration

STUDY QUESTIONS

1. When you registered for this course you had to go through a registration process. Think of this process from the standpoint of your university or college. Identify elements of the process for which process design or redesign is needed.
2. Compare the process of preparing and serving your own lunch at home with the process of preparing and serving lunch to others at a local pizza parlor. What inputs in terms of materials, human effort, and equipment are involved in each process? How are these inputs similar? How are they different?
3. "Process design choices cannot be isolated from decisions in other areas of operations management." Comment on this statement from the standpoint of a bookstore manager. *Hint:* Look over the table of contents to get some ideas.
4. How much capital intensity do you recommend for a business having an extremely unpredictable

product demand? How much vertical integration? Explain.

5. S. The number of mail order businesses has increased dramatically in the United States in the last ten years. Compare the processes of a business selling ski equipment and clothing by direct mail to the processes of a retail store handling the same items. How do they differ in terms of capital intensity, resource flexibility, vertical integration, and customer involvement? How are they the same?
6. Suppose that you and a friend decide to start a business selling sandwiches and snacks in college dormitories late at night. What decisions must you make regarding vertical integration? How will your customers be involved in your process?
7. Suppose that a grocery store has decided to add an in-store bakery. The next decision to be made is whether to install a drive-in window for the bakery so that customers do not have to enter the store in order to purchase baked goods. The store manager expects that this window would do a high volume of business early in the morning, as people purchase donuts on their way to work. How is this window likely to affect other processes in the store? What processes will bakery employees have to perform that they would not otherwise? How would customer involvement differ from that in the rest of the grocery operations?
8. King Soopers Bakery anticipates a peak demand for holiday cakes in December. What implications does this have for its use of its work force? Should part-timers be hired? Should there be more cross-training?
9. King Soopers' management is considering offering customers a "menu" of 10 different custom cake options from which to choose. How might this change affect the custom cake line?

PROBLEMS

Review Problems

1. Goliath Manufacturing must implement a manufacturing process that reduces the amount of toxic by-products. Two processes have been identified that provide the same level of toxic by-product reduction. The first process will incur $205,000 of fixed cost and $650 per unit of variable cost. The second process has a fixed cost of $145,000 and a variable cost of $800 per unit.
   a. What is the break-even quantity beyond which the first process is more attractive?
   b. What is the difference in total cost if the quantity produced is 500 units?
2. Dr. Wilson (see Applications 5.5 and 5.6) estimates that adding two new chairs will increase fixed cost by $105,000, including the annual equivalent cost of the capital investment and the salary of one more technician. Each new patient is expected to bring in $1925 per year in additional revenue, with variable cost estimated at $250 per patient. The two new chairs will allow him to expand his practice by as many as 200 patients annually. How many patients would have to be added for the new process to break even?
3. Hahn Manufacturing has been purchasing a key component of one of its products from a local supplier. The current purchase price is $1500 per unit. Efforts to standardize parts have succeeded to the point that this same component can now be used in five different products. Annual component usage should increase from 150 to 750 units. Management wonders whether it is time to make the component in-house, rather than to continue buying it from the supplier. Fixed cost would increase by about $40,000 per year for the new equipment and tooling needed. The cost of raw materials and variable overhead would be about $1100 per unit, while labor cost would go up by another $300 per unit produced.
   a. Should Hahn make rather than buy?
   b. What is the break-even quantity?
   c. What other considerations might be important?
4. A construction company is trying to decide whether to continue renting or to buy a concrete pump for its foundation and slab construction. The fixed annual cost for buying a new pump with hose and all other accessories is $8800, and annual maintenance costs would be another $2000 per year. One of the company's current employees would operate the pump, at a wage rate of $35 per hour. If the company doesn't buy the pump, it will continue to rent one for $125 per hour, including operator labor cost. The pump is normally needed for eight hours per pour.
   a. What is the break-even quantity, in number of pours?

b. If the company expects to have 40 pours per year, should it buy or continue to rent? What is the difference in annual costs at this volume?

5. Suppose that you are in charge of a large mailing to the alumni of your college inviting them to contribute to a scholarship fund. The letters and envelopes have been individually addressed (mailing labels were not used). The letters are to be folded and stuffed into the correct envelope, the envelopes are to be sealed, and a large commemorative stamp is to be placed in the upper right-hand corner of each envelope. Make a process chart for this activity, assuming that it is a one-person operation. Estimate how long it will take to stuff, seal, and stamp 2000 envelopes. Assume that the person doing this work is paid $8.00 per hour. How much will it cost to process 2000 letters, based on your time estimate? Consider how each of the following changes individually would affect the process.

   - Each letter has the greeting "Dear Alumnus or Alumna," instead of the person's name.
   - Mailing labels are used and have to be put on the envelopes.
   - Prestamped envelopes are used.
   - Envelopes are to be stamped by a postage meter.
   - Window envelopes are used.
   - A preaddressed envelope is included for contributions.

   a. Which of these changes would reduce the time and cost of the process?

   b. Would any of these changes be likely to reduce the effectiveness of the mailing? If so, which ones? Why?

   c. Would the changes that increase time and cost be likely to increase the effectiveness of the mailing? Why?

   d. What other factors need to be considered for this project?

6. Prepare a multiple activity chart for a hypothetical worker whose job is to load and unload two dry cleaning machines (call them machines A and B). Use the following conditions.

   - It is the beginning of the day, and all machines are empty.
   - The machines are identical.
   - Each machine takes 2 minutes to load and 3 minutes to unload.

   The machines run for 16 minutes each time they are loaded. The worker starts by loading machine A and then machine B. The machines are close enough together that the travel time from one to the other can be ignored. After the initial loading, the worker unloads and reloads each machine as soon as the machine stops running or as soon as the worker is available. (In other words, the worker does not waste time.)

   a. Complete the multiple activity chart for the two machines and for the worker for one hour. Calculate the utilization (percentage) for each.

   b. Assume that the machines are not turned off until the end of the day. What is the percentage utilization of the machines and the worker for the second hour and every hour thereafter?

7. Suppose that the dry cleaning worker in Problem 6 is given three machines to tend. Complete a multiple activity chart for three machines and one worker under the same conditions.

   a. What is the percentage utilization of the worker and the machines? Compare your answer to that obtained for two machines.

   b. Is it possible, hypothetically, for a worker to be utilized 100 percent? Is it possible practically? What would you likely observe if you watched a person actually working at 100 percent utilization?

8. Diagrams of two self-service gasoline stations, both located on corners, are shown in Figure 0.9 (a) and (b). Both have two rows of four pumps and a booth in which an attendant receives payment for the gasoline. At neither station is it necessary for the customer to pay in advance. The exits and entrances are marked on the diagrams. Analyze the flows of cars and people through each station.

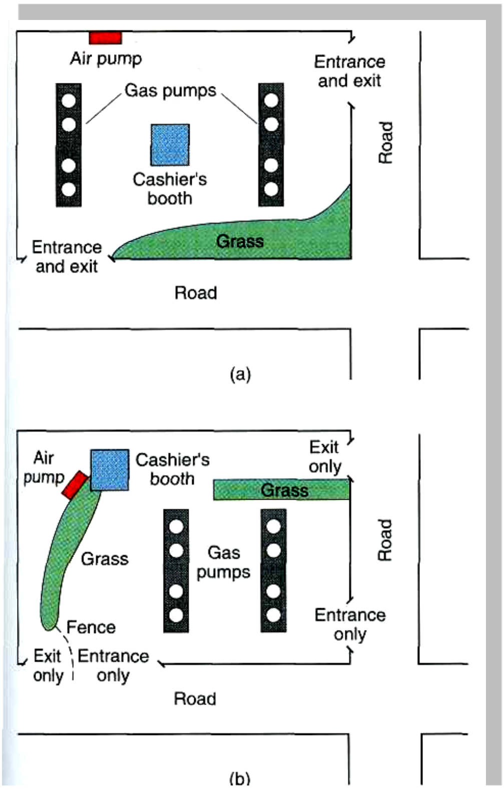


Figure 0.9

a. Which station has the most efficient flows from the standpoint of the customer?

b. Which station is likely to lose the most sales from potential customers who cannot gain access to the pumps because another car is headed in the other direction?

c. At which station can a customer pay without getting out of the car?

9. You have been asked by the management of Just Like Home restaurant to analyze some of its processes. One of these processes is making a single-scoop ice cream cone. Cones can be ordered by a server (for table

service) or by a customer (for take-out). Figure 0.10 illustrates the process chart for this operation.

Process: MAKING ONE SINGLE-SCOOP ICE-CREAM CONE
Subject charted: SERVER AT COUNTER
Beginning: WALK TO CONE STORAGE AREA
Ending: GIVE SERVER OR CUSTOMER THE CONE

Summary

Activity		Number of Steps	Time	Distance
Operation	●	6	1.70	–
Transport	➡	6	0.80	76
Inspect	■	1	0.25	–
Delay	◗	1	0.50	–
Store	▼	0	–	–

Step No.	Time (min)	Distance (ft)	●	➡	■	◗	▼	Step Description
1	0.20	5		X				WALK TO CONE STORAGE AREA
2	0.05		X					REMOVE EMPTY CONE
3	0.10	5		X				WALK TO COUNTER
4	0.05		X					PLACE CONE IN HOLDER
5	0.20	8		X				WALK TO SINK AREA
6	0.50					X		ASK DISHWASHER TO WASH SCOOP
7	0.15	8		X				WALK TO COUNTER WITH CLEAN SCOOP
8	0.05		X					PICK UP EMPTY CONE
9	0.10	2.5		X				WALK TO FLAVOR ORDERED
10	0.75		X					SCOOP ICE CREAM FROM CONTAINER
11	0.75		X					PLACE ICE CREAM IN CONE
12	0.25				X			CHECK FOR STABILITY
13	0.05	2.5		X				WALK TO ORDER PLACEMENT AREA
14	0.05		X					GIVE SERVER OR CUSTOMER THE CONE

Figure 0.10

- The ice cream counter server earns $10 per hour (including variable fringe benefits).
- The process is performed 10 times per hour (on average).
- The restaurant is open 363 days a year, 10 hours a day.

a. What is the total labor cost associated with the process?

b. How can this operation be made more efficient? Draw a process chart of the improved process. What are the annual labor savings if this new process is implemented?

Advanced Problems

Supplement Connections: Problems 11-17 require prior reading of Supplement 1 (Financial Analysis); Problems 18 and 19, Supplement 2 (Linear Programming); Problems 20-25, Supplement 4 (Queuing Models); and Problem 26, Supplement 5 (Simulation Analysis). A computer package is useful for all problems except 10, 18, and 26, and one is mandatory for Problem 19.

10. Make a multiple activity chart for a pizza baker who is assembling pizzas and baking them in two ovens that each hold two pizzas. Assume that demand for the pizzas is so high that all possible output will be used. Use the following conditions.

    - Each pizza takes 5 minutes to assemble.
    - Pizzas must bake for 17 minutes and be removed promptly.
    - It takes one minute to put a pizza in the oven and one minute to take it out. Assume that this does not prolong the baking time for any other pizza in the oven.
    - An oven may be opened to put in a pizza or take one out, even if another pizza is baking.
    - is time to take another out of the oven, the assembly process is interrupted. The baker then continues assembling the first pizza.
    - Prepare a multiple activity chart for the baker and ovens from 5:00 P.M. until 6:30 P.M. Assume that the ovens are hot but empty at 5:00 P.M.

a. How many pizzas can the baker turn out in this period of time?

b. How many pizzas are in the oven at 6:30 P.M.?

c. What is the percentage utilization of each oven shelf?

d. What percentage of the time is each oven being used (with one or two pizzas in it)?

e. What is the percentage utilization of the baker?

Hint: You will probably need a column for each shelf of each oven and one for the baker. Use any symbols that you think are appropriate.

11. John's Auto Works specializes in major body work that requires repainting the entire automobile after the body work is complete. John's present spray booth is operated by two mechanics, each earning $25 per hour. The processing times per automobile follow:

    - Sanding and preparation takes 15 minutes.
    - Taping and masking takes 5 minutes.
    - Spraying takes 10 minutes for one color, and 5 more minutes for a second color.
    - Baking takes 10 minutes.
    - Cleanup and driving to the parking area takes 5 minutes.
    - John is contemplating buying a new spray booth that would reduce spraying time to 5 minutes for one color and 3 minutes for a second color. Only one mechanic would be required for the spraying and baking operation, although two would still be required for the other operations. The second mechanic could help in another area while spraying and baking operations are underway.

    a. Prepare a multiple activity chart to show the utilization of the old and newly proposed spray booths. Assuming that only one 2-color automobile is normally painted per day, at the beginning of the day, how many can be painted in each booth in an 8-hour day?

    b. John has been offered a special price of $45,000 if he buys the new booth now. His current booth is in good shape, would last another eight years, and has a salvage value of $12,500. Assume that John's after-tax gross margin is $100 per automobile and volume is sufficient to utilize either booth to its maximum capacity during an 8-hour day. What is the net annual savings of this investment? What is its payback period?

12. A local restaurant is considering adding a salad bar. Application Sl.l (see Supplement 1) gives the related data and assumptions. Table Sl.l shows the NPV financial analysis.

    Another option (instead of the salad bar), to assemble, store, and sell preassembled salads, would require an investment outlay of $6000 to remodel the kitchen. The price and variable cost of each salad would drop to $2.25 and $1.50, respectively. Fixed cost (excluding depreciation) would be $900, since there is no longer a need to hire someone to stock the salad bar. The other assumptions about total demand, project life, tax rate, hurdle rate, salvage value, and depreciation method remain unchanged.

    a. Based on the NPV method, is the salad bar or preassembled salad option best?

    b. What is the payback period for each option?

    c. c What other factors might influence your decision?

13. Suppose that the demand estimate for salads in Problem 12 is revised upward to 36,000 salads per year.

    a. Evaluate both options using the NPV method.

    b. Evaluate both options using the payback method.

    c. Does the higher demand estimate change any of your conclusions?

14. A restaurant is considering adding an ice cream sundae bar to allow customers to create their own desserts. The investment to remodel the dining area would be $18,000, and annual demand is estimated to be 12,000 desserts. The price and variable cost per sundae are $3.75 and $2.15, respectively. Fixed costs, other than depreciation, for the energy to operate the refrigerated unit and for a new part-time employee would be $9000. The project would last four years, with no salvage value. The tax rate is 30 percent, and management wants to earn a return of at least 16 percent.

    a. Based on the NPV method, should the sundae bar project be funded?

b. Based on the payback method, should it be funded?

c. Do your conclusions change if the demand forecast is revised upward to 40,000 desserts per year?

15. Dr. Wilson, an orthodontist, is considering expanding his office from four to six chairs. Each chair requires an investment of $200,000. He will have to hire one new technician at $18,000 per year. Other additional costs are expected to be negligible. The two new chairs will allow him to expand his practice by 200 patients per year. Each new patient is expected to bring in $1500 per year in before-tax revenue. Dr. Wilson will depreciate the chairs over a five-year period, after which they are expected to have no value. Assume that Dr. Wilson is in the 50 percent tax bracket and requires a return of 20 percent on an investment. Calculate the following:

a. The incremental after-tax cash flows attributable to the two new chairs

b. The net present value of the investment c The payback period

c. The number of new patients Dr. Wilson will have to add to break even (before taxes) on an annual basis

16. The owner of a bowling alley is thinking about adding pool tables, which would require an investment of $12,000. The owner expects to generate incremental after-tax cash flows of $4000 for each of the next five years by having pool tables at the bowling alley. What is the present value of the stream of expected cash flows? (Use 16 percent for the hurdle rate.)

a. What is the net present value?

b. What is the payback period?

c. What advice would you give the owner about the proposed investment?

d. What other issues should the owner consider?

17. Catherine Lerme, owner of Super Quick Car Care, is considering expanding her garage from four to six bays. Each bay requires an investment in tools and a hydraulic lift of $125,000. She will also have to hire a new mechanic for each bay at $17,000 per year. Other additional costs are expected to be negligible. The two new bays will allow her to service an additional 1800 automobiles per year. Each additional automobile serviced is expected to bring in an average of $100 in before-tax revenue. Lerme will depreciate the equipment and tools over a five-year period, after which they will have no salvage value. Super Quick Car Care has a tax rate of 30 percent and requires a 20 percent return on investment. Calculate the following:

a. The incremental after-tax cash flows attributable to the two new bays

b. The net present value of the investment

c. The payback period

d. The number of additional cars that Super Quick must service annually to break even (before taxes)

18. The manufacturer of textile dyes can use two different processing routings for a particular type of dye. Routing 1 uses drying press A, and routing 2 uses drying press B. Both routings require the same mixing vat to blend chemicals for the dye before drying. The following table shows the time requirements and capacities of these processes.

	Hours per Kilogram		Capacity
Process	Routing 1	Routing 2	(hr)
Mixing	2	2	54
Dryer A	6	0	120
Dryer B	0	8	180

In addition, each kilogram of dye processed on routing 1 uses 20 liters of chemicals, whereas each kilogram of dye processed on routing 2 uses only 15 liters. The difference results from differing yield rates of the drying presses. Consequently, the profit per kilogram processed on routing 1 is $50 and on routing 2 is $65. A total of 450 liters of input chemicals is available.

a. Write the constraints and objective function for this problem to maximize profits.

b. Use the graphic method of linear programming to find the optimal solution.

19. Use the simplex method to solve Problem 18, both manually and on the computer.

20. The Howard, Smith, and Parke law firm produces many legal documents that must be typed for clients and the firm. Requests average four pages of documents per hour and arrive according to a Poisson distribution. The secretary can type five pages per hour on average according to an exponential distribution.

    a. What is the average utilization rate of the secretary?

    b. What is the probability that more than four pages of documents are waiting or being typed?

    c. c What is the average number of documents waiting to be typed?

    d. What is the average waiting time for documents in queue?

21. An automobile manufacturer uses a welding robot in its assembly line. Cars arrive at the welding station at a rate of 120 per hour according to a Poisson distribution. The speed of the welding robot can be adjusted, although actual welding time depends on the particular model of car being assembled. Setting the robot too fast causes more defects, whereas setting it too slow causes bottlenecks in assembly. Regardless of the speed, the robot's average time required to weld is exponentially distributed. Answer the following questions, assuming that the single-server queuing model applies:

    a. At what average service rate should the robot be set to ensure a 30 percent chance that three or more cars are in queue or being welded?

    b. What is the average time a car spends at this weld station?

    c. What is the average number of cars waiting to be welded?

22. Dr. Weston is a dentist who oversees the training of new dental students in a local clinic serving the needs of the general public. The clinic has three dental chairs, each manned by a student, and patients arrive at the rate of five per hour according to the Poisson distribution. The average time required for a dental checkup is 30 minutes according to an exponential distribution.

    a. What is the probability that there will be no patients in the clinic?

    b. What is the probability that there will be six or more patients in the clinic?

    c. What is the average number of patients waiting in queue?

    d. What is the average waiting time in queue?

23. The Hairy Knoll is a discount barbershop where the students from the Kingston Barber School serve their apprenticeship. The shop has only three barber chairs, each manned by an eager student. An instructor oversees the operation and gives guidance as needed. Patrons are served on a first-come, first-served basis and arrive at the rate of ten customers per hour according to a Poisson distribution. The time required for a haircut averages 15 minutes according to an exponential distribution.

    a. What is the probability that there will be no customers in the shop?

    b. What is the probability that there will be five or more customers in the shop?

    c. What is the average number of customers waiting in queue?

    d. What is the average waiting time in queue?

24. Consider further the Hairy Knoll barbershop described in Problem 23. Suppose that it is desirable to allow the students idle time so they can sweep the floor and be given additional instruction in cutting hair. The dean of the Kingston Barber School believes that the added expense of remodeling the Hairy Knoll to accommodate four barber chairs could be offset by slightly increased prices, if the average waiting time in queue per customer is less than five minutes. Assuming that the price change will not affect the rate of customer arrivals, should the Hairy Knoll be remodeled?

25. The tool crib supervisor at Ace Electronics wishes to determine the staffing policy that minimizes total operating costs. The average arrival rate at the crib, where tools are dispensed to the workers, is 8 machinists per hour; each machinist's pay is $18 per hour. The supervisor can staff the crib either with a junior attendant who is paid $5 per hour and can process 10 arrivals per hour or with a senior attendant who is paid $9 per hour and can process 12 arrivals per hour. Which type should be selected, and what is the total estimated hourly cost?

26. Eagle Dry Cleaners specializes in same-day dry cleaning. Customers drop off their garments early in

the morning and expect them to be ready for pickup on their way home from work. There is a risk, however, that the work needed on a given garment cannot be done that day, depending on the type of dry cleaning required and the toughness of extraordinary stains. Historically, an average of 15 garments had to be held over to the next day. The store manager is contemplating expanding to reduce or eliminate that backlog. A simulation model was developed with the following distribution for garments per day:

Number	Probability	Random Numbers
50	0.10	00-09
60	0.25	10-34
70	0.30	35-64
80	0.25	65-89
90	0.10	90-99

With expansion, the maximum number of garments that could be dry cleaned per day is:

Number	Probability	Random Numbers
60	0.30	00-29
70	0.40	30-69
80	0.30	70-99

In the simulation for a specific day, the number of garments needing cleaning (NGNC) is determined first. Next, the maximum number of garments that could be dry cleaned (MNGD) is determined. If MNGD < NGNC, all garments are dry cleaned for that day. If MNGD < NGNC, then (NGNC — MNGD) garments must be added to the number of garments arriving the next day to obtain the NGNC for the next day. The simulation continues in this manner until a specific number of days have been simulated.

1. Assuming that the store is empty at the start, simulate 15 days of operation using the following random numbers (the first determines the number of arrivals and the second the capacity):

   (49, 77), (27, S3), (65, 08), (83,12), (04, 82),

   (58, 44), (53, 83), (57, 72), (32, 53), (60, 79),

   (79, 30), (41, 48), (97, 86), (30, 25), (80, 73)

   What is the average daily number of garments held overnight, based on your simulation?

2. If the cost associated with garments being held over is $25 per garment per day and the added cost of expansion is $100 per day, is the expansion a good idea?

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QUESTIONS

What is process design?

What is capital intensity in process design?

What is resource flexibility?

What is vertical integration?

What is customer involvement?

What was the relationship between capital intensity and resource flexibility in the past?

Inverse

What was the problem of General Electric plant in Lynn, Massachusetts?

They relied on Pentagon orders for plane engines, but it didn’t happen to the extent it was expected.

What is a family of skills?

How does need for volume flexibility affect the workforce flexibility?