

Chapter 4

Strategic capacity planning

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I. Introduction

Capacity planning is a key strategic component in designing the system. It encompasses many basic decisions with long-term consequences for the organization. The decisions made in the product or service design stage have major implications for capacity planning.

Capacity refers to an upper limit or ceiling on the load that an operating unit can handle. The load might be in terms of the number of physical units produced (e.g., bicycles assembled per hour) or the number of services performed (e.g., computers upgraded per hour). The operating unit might be a plant, department, machine, store, or worker. Capacity needs include equipment, space, and employee skills.

The goal of **strategic capacity planning** is to achieve a match between the long-term supply capabilities of an organization and the predicted level of long-term demand. Organizations become involved in capacity planning for various reasons. Among the chief reasons are changes in demand, changes in technology, changes in the environment, and perceived threats or opportunities. A gap between current and desired capacity will result in capacity that is out of balance. **Overcapacity** causes operating costs that are too high, while **undercapacity** causes strained resources and possible loss of customers.



II. Capacity decisions are strategic

For a number of reasons, capacity decisions are among the most fundamental of all the design decisions that managers must make. In fact, capacity decisions can be critical for an organization:

- 1.** Capacity decisions have a real impact on the ability of the organization to meet future demands for products and services; capacity essentially limits the rate of output possible. Having capacity to satisfy demand can often allow a company to take advantage of tremendous benefits.
- 2.** Capacity decisions affect operating costs. Ideally, capacity and demand requirements will be matched, which will tend to minimize operating costs. In practice, this is not always achieved because actual demand either differs from expected demand or tends to vary (e.g., cyclically). In such cases, a decision might be made to attempt to balance the costs of over- and undercapacity.
- 3.** Capacity is usually a major determinant of initial cost. Typically, the greater the capacity of a productive unit, the greater its cost. This does not necessarily imply a one-for-one relationship; larger units tend to cost proportionately less than smaller units.



4. Capacity decisions often involve long-term commitment of resources and the fact that, once they are implemented, those decisions may be difficult or impossible to modify without incurring major costs.
5. Capacity decisions can affect competitiveness. If a firm has excess capacity, or can quickly add capacity, that fact may serve as a barrier to entry by other firms. Then too, capacity can affect delivery speed, which can be a competitive advantage.
6. Capacity affects the ease of management; having appropriate capacity makes management easier than when capacity is mismatched.
7. Globalization has increased the importance and the complexity of capacity decisions. Far-flung supply chains and distant markets add to the uncertainty about capacity needs.
8. Because capacity decisions often involve substantial financial and other resources, it is necessary to plan for them far in advance. For example, it may take years for a new powergenerating plant to be constructed and become operational. However, this increases the risk that the designated amount of capacity will not match actual demand when the capacity becomes available.



III. Defining and measuring capacity

Capacity often refers to an upper limit on the rate of output. Where only one product or service is involved, the capacity of the productive unit may be expressed in terms of that item. However, when multiple products or services are involved, as is often the case, using a simple measure of capacity based on units of output can be misleading.

Business	Inputs	Outputs
Auto manufacturing	Labor hours, machine hours	Number of cars per shift
Steel mill	Furnace size	Tons of steel per day
Oil refinery	Refinery size	Gallons of fuel per day
Farming	Number of acres, number of cows	Bushels of grain per acre per year, gallons of milk per day
Restaurant	Number of tables, seating capacity	Number of meals served per day
Theater	Number of seats	Number of tickets sold per performance
Retail sales	Square feet of floor space	Revenue generated per day



- ❑ **Design capacity:** The maximum output rate or service capacity an operation, process, or facility is designed for.
- ❑ **Effective capacity:** Design capacity minus allowances such as personal time, and maintenance.

Design capacity is the maximum rate of output achieved under ideal conditions. **Effective capacity** is always less than design capacity owing to realities of changing product mix, the need for periodic maintenance of equipment, lunch breaks, coffee breaks, problems in scheduling and balancing operations, and similar circumstances. **Actual output** cannot exceed effective capacity and is often less because of machine breakdowns, absenteeism, shortages of materials, and quality problems, as well as factors that are outside the control of the operations managers.

These different measures of capacity are useful in defining two measures of system effectiveness: **efficiency** and **utilization**.

Efficiency is the ratio of actual output to effective capacity. **Capacity utilization** is the ratio of actual output to design capacity.

$$\text{Efficiency} = \frac{\text{Actual output}}{\text{Effective capacity}} \times 100$$

$$\text{Utilization} = \frac{\text{Actual output}}{\text{Design capacity}} \times 100$$



Example

1. Given the following information, compute the efficiency and the utilization of the vehicle repair department:

- Design capacity = 50 trucks per day
- Effective capacity = 40 trucks per day
- Actual output = 36 trucks per day

2. A department works one 8-hour shift, 250 days a year, and has these figures for usage of a machine that is currently being considered:

Product	Annual Demand	Standard Processing Time per unit (Hr)
1	400	5.0
2	300	8.0
3	700	2.0



IV. Evaluating alternatives

An organization needs to examine **alternatives** for future capacity from a number of different perspectives. Most obvious are economic considerations: Will an alternative be economically feasible? How much will it cost? How soon can we have it? What will operating and maintenance costs be? What will its useful life be? Will it be compatible with present personnel and present operations?

Less obvious, but nonetheless important, is possible negative public opinion. For instance, the decision to build a new power plant is almost sure to stir up reaction. Any option that could disrupt lives and property is bound to generate hostile reactions. Construction of new facilities may necessitate moving personnel to a new location. Embracing a new technology may mean retraining some people and terminating some jobs. Relocation can cause unfavorable reactions, particularly if a town is about to lose a major employer. Conversely, community pressure in a new location may arise if the presence of the company is viewed unfavorably (noise, traffic, pollution).

A number of techniques are useful for evaluating capacity alternatives from an economic standpoint. Some of the more common are **cost–volume analysis**, financial analysis, **decision theory**, and waiting-line analysis.



IV.1. Cost–Volume Analysis

Cost–volume analysis focuses on relationships between cost, revenue, and volume of output.

The purpose of cost–volume analysis is to estimate the income of an organization under different operating conditions. It is particularly useful as a tool for comparing capacity alternatives.

Use of the technique requires identification of all costs related to the production of a given product. These costs are then designated as fixed costs or variable costs.

- ❑ **Fixed costs** tend to remain constant regardless of volume of output. Examples include rental costs, property taxes, equipment costs, heating and cooling expenses, and certain administrative costs.
- ❑ **Variable costs** vary directly with volume of output. The major components of variable costs are generally materials and labor costs. We will assume that variable cost per unit remains the same regardless of volume of output, and that all output can be sold.



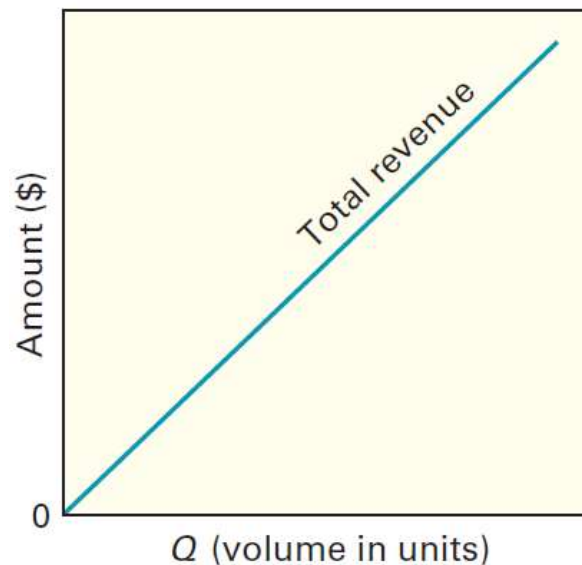
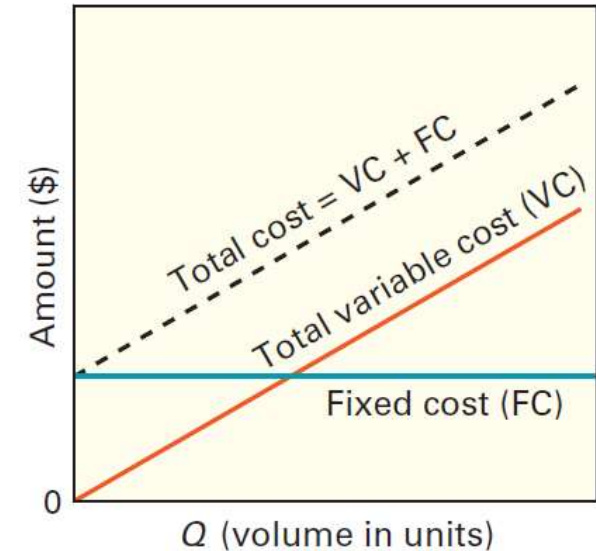
The total cost associated with a given volume of output is equal to the sum of the fixed cost and the variable cost per unit times volume:

$$TC = FC + VC$$

$$VC = Q \times v$$

Revenue per unit, like variable cost per unit, is assumed to be the same regardless of quantity of output. Total revenue will have a linear relationship to output. The total revenue associated with a given quantity of output, Q , is

$$TR = R \times Q$$



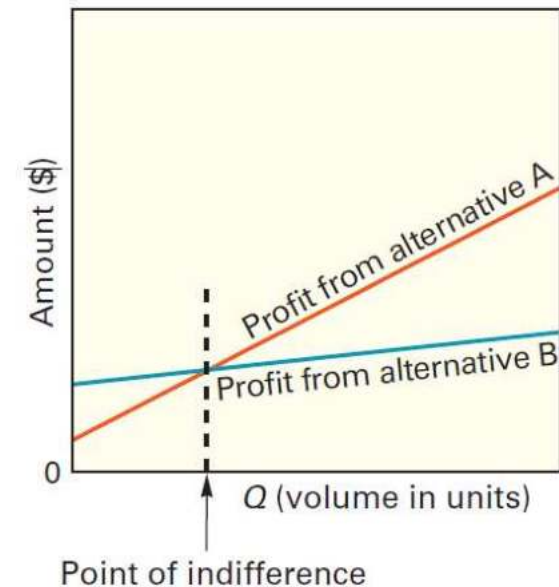
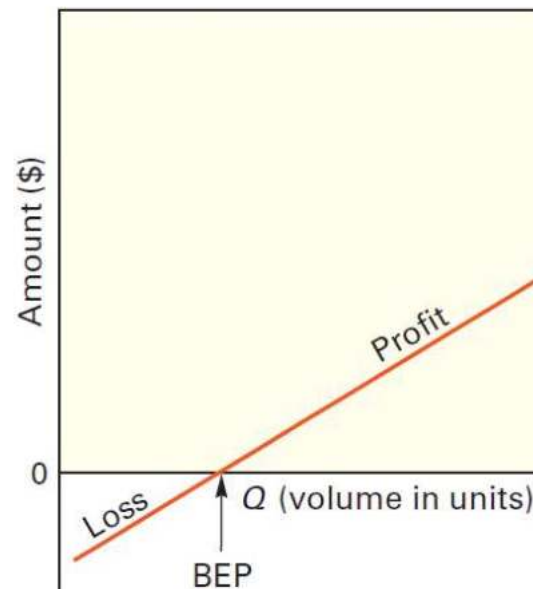
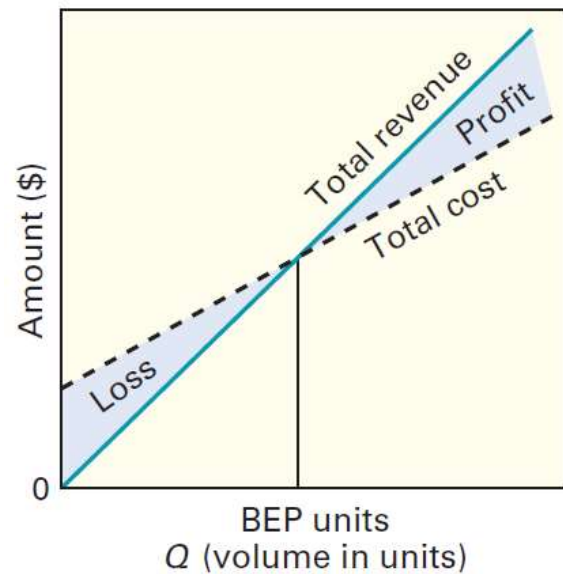
FC = Fixed cost
 VC = Total variable cost
 v = Variable cost per unit
 TC = Total cost
 TR = Total revenue
 R = Revenue per unit
 Q = Quantity or volume of output
 Q_{BEP} = Break-even quantity
 P = Profit



The **profit** is the difference between total revenue and total (i.e., fixed plus variable) cost. The volume at which total cost and total revenue are equal is referred to as the **break-even point (BEP)**. When volume is less than the break-even point, there is a loss; when volume is greater than the break-even point, there is a profit.

Total profit can be computed using the formula

$$P = TR - TC = R \times Q - (FC + v \times Q) = Q(R - v) - FC$$



The difference between revenue per unit and variable cost per unit, $R - v$, is known as the **contribution margin**.

The required volume, Q , needed to generate a specified profit is

$$Q = \frac{P + FC}{R - v}$$

A special case of this is the volume of output needed for total revenue to equal total cost. This is the break-even point, computed using the formula

$$Q_{BEP} = \frac{FC}{R - v}$$



Example

The owner of Old-Fashioned Berry Pies is contemplating adding a new line of pies, which will require leasing new equipment for a monthly payment of \$6,000. Variable costs would be \$2 per pie, and pies would retail for \$7 each.

- a. How many pies must be sold in order to break even?
- b. What would the profit (loss) be if 1,000 pies are made and sold in a month?
- c. How many pies must be sold to realize a profit of \$4,000?
- d. If 2,000 can be sold, and a profit target is \$5,000, what price should be charged per pie?



Example

A manager has the option of purchasing one, two, or three machines. Fixed costs and potential volumes are as follows (Variable cost is 10 SAR per unit, and revenue is 40 SAR per unit.) :

Number of machines	Total Annual Fixed cost	Corresponding range of output
1	9,600 SAR	0 to 300
2	15,000 SAR	301 to 600
3	20,000 SAR	601 to 900

- a. Determine the break-even point for each range.
- b. If projected annual demand is between 580 and 660 units, how many machines should the manager purchase?



IV.2. Decision theory

Decision theory represents a general approach to **decision making**. It is suitable for capacity planning, product and service design, equipment selection, and location planning. Decisions tend to be characterized by the following elements:

1. A set of possible future conditions that will have a bearing on the results of the decision.
2. A list of alternatives for the manager to choose from.
3. A known payoff for each alternative under each possible future condition.

To use this approach, a decision maker would employ this process:

1. Identify the possible future conditions (e.g., demand will be low, medium, or high; the competitor will or will not introduce a new product). These are called states of nature.
2. Develop a list of possible alternatives, one of which may be to do nothing.
3. Determine or estimate the payoff associated with each alternative for every possible future condition.
4. If possible, estimate the likelihood (probability) of each possible future condition.
5. Evaluate alternatives according to some decision criterion (e.g., maximize expected profit), and select the best alternative.



The information for a decision is often summarized in a **payoff table**, which shows the expected payoffs for each alternative under the various possible states of nature. These tables are helpful in choosing among alternatives because they facilitate comparison of alternatives.

Alternatives	Possible future demand (millions SAR)		
	Low	Moderate	High
Small facility	10	10	10
Medium facility	7	12	12
Large facility	-4	2	16

The payoffs are shown in the body of the table. In this instance, the payoffs are in terms of present values, which represent expected future income less costs. This is a convenient measure because it places all alternatives on a comparable basis.

The problem for the decision maker is to select one of the alternatives, taking the present value into account. **Evaluation of the alternatives differs according to the degree of certainty associated with the possible future conditions.**



Causes of poor decisions

Despite the best efforts of a manager, a decision occasionally turns out poorly due to unforeseeable circumstances. Luckily, such occurrences are not common. Often, failures can be traced to a combination of mistakes in the decision process, to **bounded rationality**, or to **suboptimization**.

The decision process consists of these steps:

1. Identify the problem.
2. Specify objectives and criteria for a solution.
3. Develop suitable alternatives.
4. Analyze and compare alternatives.
5. Select the best alternative.
6. Implement the solution.
7. Monitor to see that desired result is achieved.



Decision environments

Operations management decision environments are classified according to the degree of certainty present. There are three basic categories: certainty, risk, and uncertainty.

- ❑ **Certainty** means that relevant parameters such as costs, capacity, and demand have known values.

*Profit per unit is \$5. You have an order for 200 units. How much profit will you make? (This is an example of **certainty** since unit profits and total demand are known.)*

- ❑ **Risk** means that certain parameters have probabilistic outcomes.

*Profit is \$5 per unit. Based on previous experience, there is a 50 percent chance of an order for 100 units and a 50 percent chance of an order for 200 units. What is expected profit? (This is an example of **risk** since demand outcomes are probabilistic.)*

- ❑ **Uncertainty** means that it is impossible to assess the likelihood of various possible future events.

*Profit is \$5 per unit. The probabilities of potential demands are unknown. (This is an example of **uncertainty**.)*

The importance of these different decision environments is that they require different analysis techniques. Some techniques are better suited for one category than for others.



Decision making under uncertainty

No information is available on how likely the various states of nature are. Under those conditions, four possible decision criteria :

- ❑ **Maximin** : Determine the worst possible payoff for each alternative, and choose the alternative that has the “best worst.” The maximin approach is essentially a **pessimistic** one because it takes into account only the worst possible outcome for each alternative. The actual outcome may not be as bad as that, but this approach establishes a “guaranteed minimum.”
- ❑ **Maximax** : Determine the best possible payoff, and choose the alternative with that payoff. The maximax approach is an **optimistic**, “go for it” strategy; it does not take into account any payoff other than the best.
- ❑ **Laplace** : Determine the average payoff for each alternative, and choose the alternative with the best average. The Laplace approach treats the states of nature as equally likely.
- ❑ **Minimax regret** : Determine the worst regret for each alternative, and choose the alternative with the “best worst.” This approach seeks to minimize the difference between the payoff that is realized and the best payoff for each state of nature.



Decision making under risk

Between the two extremes of certainty and uncertainty lies the case of risk: The probability of occurrence for each state of nature is known. A widely used approach under such circumstances is the **expected monetary value criterion**. The expected value is computed for each alternative, and the one with the best expected value is selected.

The expected value is the sum of the payoffs for an alternative where each payoff is weighted by the probability for the relevant state of nature. Thus, the approach is **Expected monetary value (EMV)** criterion —Determine the expected payoff of each alternative, and choose the alternative that has the best expected payoff.



Example

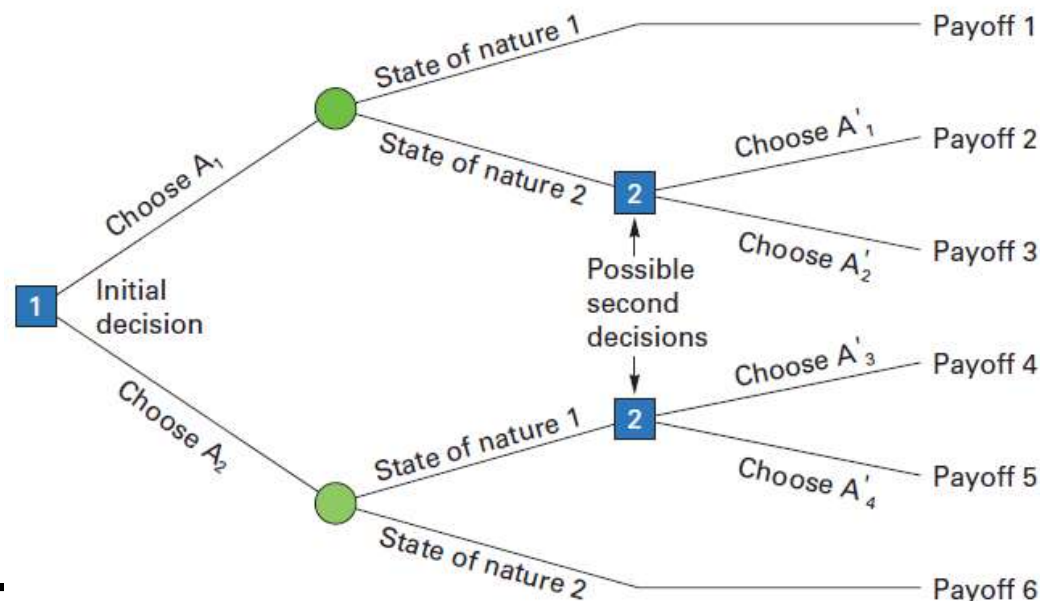
Alternatives	Possible future demand (millions SAR)		
	Low	Moderate	High
Small facility	10	10	10
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1. Determine the best alternative in the payoff table for each of the cases: It is known with certainty that demand will be (a) low, (b) moderate, (c) high.
2. determine which alternative would be chosen under each of these strategies: (a) Maximin, (b) Maximax, (c) Laplace, (d) minimax regret.
3. Using the expected monetary value criterion, identify the best alternative for the previous payoff table for these probabilities: low = .30, moderate =.50, and high =.20.

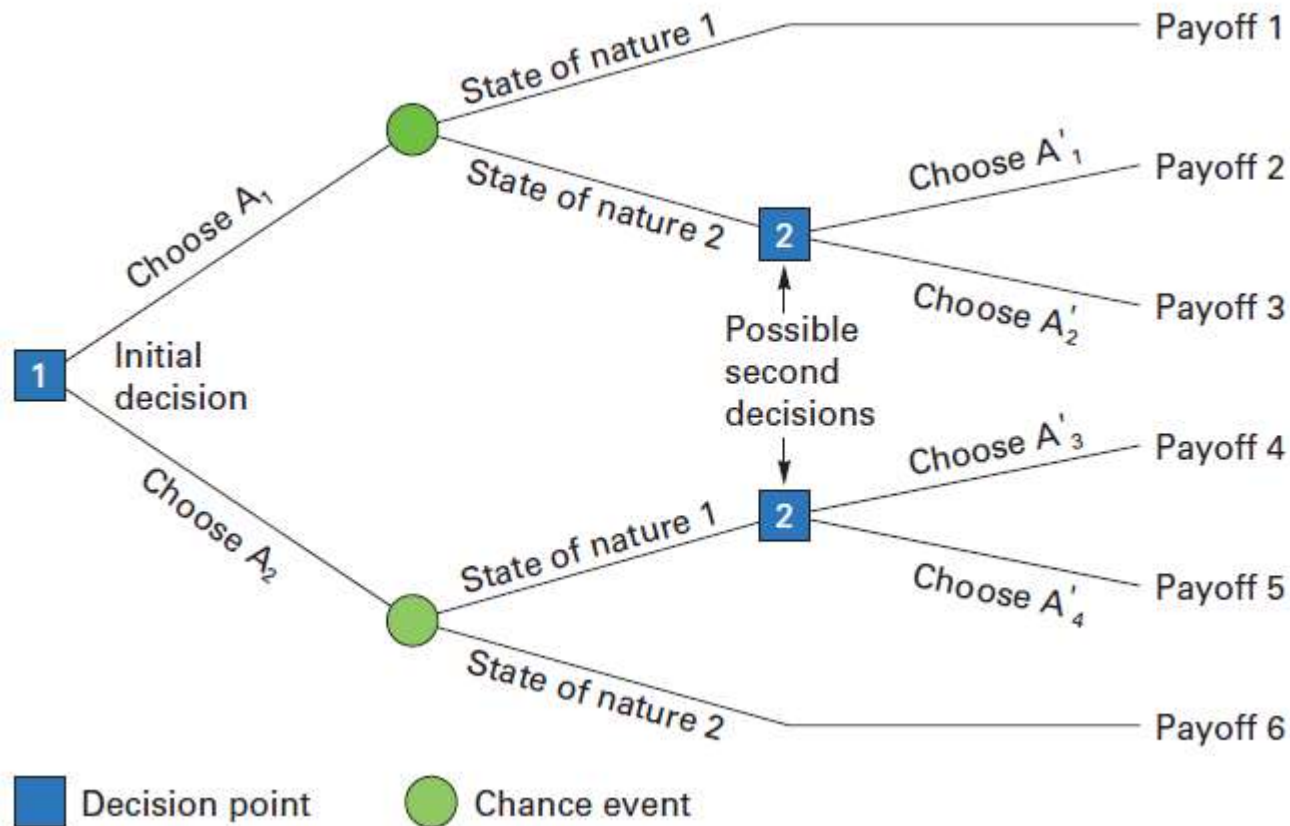


Decision tree

A decision tree is a **schematic representation** of the alternatives available to a decision maker and their possible consequences. The term gets its name from the treelike appearance of the diagram. Although tree diagrams can be used in place of a payoff table, they are particularly useful for analyzing situations that involve sequential decisions. A decision tree is composed of a number of nodes that have branches emanating from them. **Square nodes** denote decision points, and **circular nodes** denote chance events. Read the tree from left to right. Branches leaving square nodes represent alternatives; branches leaving circular nodes represent chance events (i.e., the possible states of nature).



After the tree has been drawn, it is analyzed from right to left; that is, starting with the last decision that might be made. For each decision, choose the alternative that will yield the greatest return (or the lowest cost). If chance events follow a decision, choose the alternative that has the highest expected monetary value (or lowest expected cost).



Example

A manager must decide on the size of a factory to build. The manager has narrowed the choices to two: large or small. Information has been collected on payoffs, and a decision tree has been constructed. Analyze the decision tree and determine which initial alternative (build small or build large) should be chosen in order to maximize expected monetary value.

