

# An Introduction to Decision Theory

# 20



Mark Horn/Getty Images

▲ **BLACKBEARD'S PHANTOM FIREWORKS** is considering introducing two new bottle rockets. The company can add both to the current line, neither, or just one of the two. The success of these products depends on consumers' reactions. These reactions can be summarized as good, fair, or poor. The company's revenues are estimated in the payoff table in Exercise 11. Compute the expected monetary value for each decision. (See Exercise 11a and **LO20-2**.)

## LEARNING OBJECTIVES

*When you have completed this chapter, you will be able to:*

- LO20-1** Identify and apply the three components of a decision.
- LO20-2** Analyze a decision using expected monetary value.
- LO20-3** Analyze a decision using opportunity loss.
- LO20-4** Apply maximin, maximax, and minimax regret strategies to make a decision.
- LO20-5** Compute and explain the expected value of perfect information.
- LO20-6** Apply sensitivity analysis to evaluate a decision subject to uncertainty.
- LO20-7** Use a decision tree to illustrate and analyze decision making under uncertainty.

## Introduction

Decision theory is a branch of statistics that evaluates two or more decision alternatives in the face of an uncertain future. Probabilities are used to forecast the likelihood of future events. As the name implies, the focus is on the process of making decisions and explicitly includes the payoffs that may result from selecting a particular decision alternative. In contrast, classical statistics focuses on estimating a parameter, such as the population mean, constructing a confidence interval, or conducting a hypothesis test. Classical statistics does not address the consequences.

Statistical decision theory is concerned with determining which decision, from a set of possible alternatives, is optimal for a particular set of conditions. Consider the following examples of decision-theory problems.

- Ford Motor Company must decide whether to purchase assembled door locks for the 2019 Ford F-150 truck or to manufacture and assemble the door locks at its Dearborn, Michigan, plant. If sales of the F-150 truck continue to increase, it will be more profitable to manufacture and assemble the parts. If sales level off or decline, it will be more profitable to purchase the door locks assembled. Should it make or buy the door locks?
- Banana Republic developed a new line of summer rain jackets that are very popular in the cold-weather regions of the country. It would like to purchase commercial television time during the upcoming NCAA basketball final. If both teams that play in the game are from warm parts of the country, it estimates that only a small proportion of the viewers will be interested in the jackets. However, a matchup between two teams who come from cold climates would reach a large proportion of viewers who wear jackets. Should it purchase commercial television time?
- General Electric is considering three options regarding the prices of refrigerators for next year. GE could (1) raise the prices 5%, (2) raise the prices 2.5%, or (3) leave the prices as they are. The final decision will be based on sales estimates and on GE's knowledge of what other refrigerator manufacturers might do.



Rena Laverty/EPA/Shutterstock

In each of these cases, the decision is characterized by several alternative courses of action and several factors not under the control of the decision maker. For example, Banana Republic has no control over which teams reach the NCAA basketball final. These cases characterize the nature of decision making. Possible decision alternatives can be listed, possible future events determined, and even probabilities established, but the decisions are *made in the face of uncertainty*.

### LO20-1

Identify and apply the three components of a decision.

## Elements of a Decision

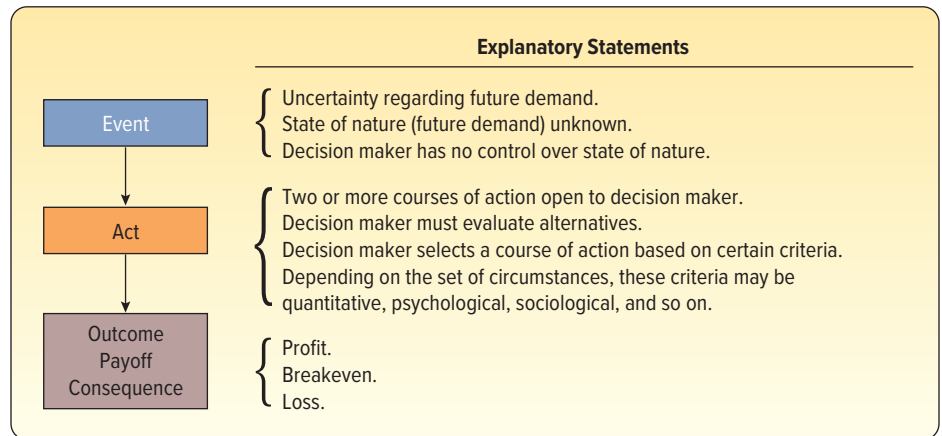
There are three components to any decision: (1) the choices available, or alternatives; (2) the states of nature, which are not under the control of the decision maker; and (3) the payoffs. These concepts will be explained in the following paragraphs.

The **alternatives**, or **acts**, are the choices available to the decision maker. Ford can decide to manufacture and assemble the door locks in Dearborn, or it can decide to purchase them. Banana Republic has two advertising alternatives: to purchase commercial television time or not. GE is considering three pricing alternatives regarding the marketing of refrigerators. To simplify our presentation, we assume the decision maker can select from a rather small number of outcomes. With the help of computers, however, the decision alternatives can be expanded to a large number of possibilities.

The **states of nature** are the uncontrollable future events. The state of nature that actually happens is outside the control of the decision maker. Ford does not know whether demand will remain high for the F-150. Banana Republic cannot determine whether warm-weather or cold-weather teams will play in the NCAA basketball final. GE does not know how competitors will price refrigerators.

A **payoff** is needed to compare each combination of decision alternative and state of nature. Ford may estimate that if it assembles door locks at its Dearborn plant and the demand for F-150 trucks is low, the payoff will be \$40,000. Conversely, if it purchases the door locks assembled and the demand is high, the payoff is estimated to be \$22,000. Banana Republic needs to estimate the payoffs for purchasing commercial television time given estimates of the potential audience for the rain jacket. GE needs to estimate the payoffs for each pricing alternative given estimates of competitors' pricing.

The main elements of the decision under conditions of uncertainty are identified schematically:



In many cases, we can make better decisions if we establish probabilities for the states of nature. These probabilities may be based on historical data or subjective estimates. Ford may estimate the probability of continued high demand as .70. Banana Republic may estimate a probability of .75 that the commercial will reach the targeted audience. GE may estimate the probability to be .25 that Amana and other manufacturers will raise the prices of their refrigerators.

### LO20-2

Analyze a decision using expected monetary value.

## Decision Making Under Conditions of Uncertainty

We begin this section with an example of decision making under uncertainty. The purpose of the example is to explain a logical process to evaluate a set of alternatives and select an alternative as the decision. The first step is to set up a payoff table.

### Payoff Table

Bob Hill, a small investor, has \$1,100 to invest. He has studied several common stocks and narrowed his choices to three, namely, Kayser Chemicals, Rim Homes, and Texas Electronics. He estimated that, if his \$1,100 were invested in Kayser Chemicals and a strong bull market developed by the end of the year (that is, stock prices increased drastically), the value of his Kayser stock would more than double, to \$2,400. However, if there was a bear market (i.e., stock prices declined), the value of his Kayser stock could conceivably drop to \$1,000 by the end of the year. His predictions regarding the value of his \$1,100 investment for the three stocks for a bull market and for a bear market are shown in Table 20–1. This table is a **payoff table**.

**TABLE 20–1** Payoff Table for Three Common Stocks under Two Market Conditions

Purchase	Bull Market, $S_1$	Bear Market, $S_2$
Kayser Chemicals ( $A_1$ )	\$2,400	\$1,000
Rim Homes ( $A_2$ )	2,200	1,100
Texas Electronics ( $A_3$ )	1,900	0

The various choices are called the **decision alternatives** or the **acts**. There are three in this situation. Let  $A_1$  be the purchase of Kayser Chemicals,  $A_2$  the purchase of Rim Homes, and  $A_3$  the purchase of Texas Electronics. Whether the market turns out to be bear or bull is not under the control of Bob Hill. These uncontrolled future events are the **states of nature**. Let the bull market be represented by  $S_1$  and the bear market by  $S_2$ .

### Expected Payoff

If the payoff table was the only information available, the investor might take a conservative action and buy Texas Electronics to be assured of at least \$1,150 at the end of the year (a slight profit). A speculative venture, however, might be to buy Kayser Chemicals, with the possibility of more than doubling the \$1,100 investment.

Any decision regarding the purchase of one of the three common stocks made solely on the information in the payoff table would ignore the valuable historical records kept by Moody's, Value Line, and other investment services relative to stock price movements over a long period. Suppose a study of these investment services revealed that during the past 10 years stock market prices increased six times and declined only four times. According to this information, the probability of a market rise is .60 and the probability of a market decline is .40.

Assuming these historical frequencies are reliable, the payoff table and the probability estimates (.60 and .40) are combined to arrive at the **expected payoff** of buying each of the three stocks. Expected payoff is also called **expected monetary value**, shortened to EMV. It can also be described as the **mean payoff**. The calculations needed to determine the expected payoff for the act of purchasing Kayser Chemicals are shown in Table 20–2.

**TABLE 20–2** Expected Payoff for the Act of Buying Kayser Chemicals, EMV ( $A_1$ )

State of Nature	Payoff	Probability of State of Nature	Expected Value
Market rise, $S_1$	\$2,400	.60	\$1,440
Market decline, $S_2$	1,000	.40	400
			<u>\$1,840</u>

To explain one expected monetary value calculation, note that if the investor had purchased Kayser Chemicals and the market prices declined, the value of the stock would be only \$1,000 at the end of the year (from Table 20–1). Past experience, however, revealed that this event (a market decline) occurred only 40% of the time. In the long run, therefore, a market decline would contribute \$400 to the total expected payoff from the stock, found by  $(\$1,000)(.40)$ . Adding the \$400 to the \$1,440 expected under rising market conditions gives \$1,840, the “expected” payoff in the long run.

These calculations are summarized as follows:

#### EXPECTED MONETARY VALUE

$$EMV(A_i) = \sum [P(S_j) \cdot V(A_i, S_j)] \quad (20-1)$$



where:

$EMV(A_i)$  refers to the expected monetary value of decision alternative  $i$ . There may be many decisions possible. We will let 1 refer to the first decision, 2 to the second, and so on. The lowercase letter  $i$  represents the entire set of decisions.

$P(S_j)$  refers to the probability of the states of nature. There can be an unlimited number, so we will let  $j$  represent this possible outcome.

$V(A_i, S_j)$  refers to the value of the payoffs. Note that each payoff is the result of a combination of a decision alternative and a state of nature.

$EMV(A_1)$ , the expected monetary value for the decision alternative of purchasing Kayser Chemicals stock, is computed by:

$$\begin{aligned} EMV(A_1) &= [P(S_1) \cdot V(A_1, S_1)] + [P(S_2) \cdot V(A_1, S_2)] \\ &= .60(\$2,400) + .40(\$1,000) = \$1,840 \end{aligned}$$

Purchasing Kayser Chemicals stock is only one possible choice. The expected payoffs for the acts of buying Kayser Chemicals, Rim Homes, and Texas Electronics are given in Table 20–3.

**TABLE 20–3** Expected Payoffs for Three Stocks

Purchase	Expected Payoff
Kayser Chemicals	\$1,840
Rim Homes	1,760
Texas Electronics	1,600

An analysis of the expected payoffs in Table 20–3 indicates that purchasing Kayser Chemicals would yield the greatest expected profit. This outcome is based on (1) the investor's estimated future value of the stocks and (2) historical experience with respect to the rise and decline of stock prices. It should be emphasized that although purchasing Kayser stock represents the best action under the expected-value criterion, the investor still might decide to buy Texas Electronics stock to minimize the risk of losing some of the \$1,100 investment.

## SELF-REVIEW 20–1



Verify the conclusion, shown in Table 20–3, that the expected payoff for the act of purchasing Rim Homes stock is \$1,760.

## EXERCISES

- The following payoff table was developed. Let  $P(S_1) = .30$ ,  $P(S_2) = .50$ , and  $P(S_3) = .20$ . Compute the expected monetary value for each of the alternatives. What decision would you recommend?

Alternative	State of Nature		
	$S_1$	$S_2$	$S_3$
$A_1$	\$50	\$70	\$100
$A_2$	90	40	80
$A_3$	70	60	90

2. Wilhelms Cola Company plans to market a new lime-flavored cola this summer. The decision is whether to package the cola in returnable or in nonreturnable bottles. Currently, the state legislature is considering eliminating nonreturnable bottles. Tybo Wilhelms, president of Wilhelms Cola Company, has discussed the problem with his state representative and established the probability to be .70 that nonreturnable bottles will be eliminated. The following table shows the estimated monthly profits (in thousands of dollars) if the lime cola is bottled in returnable versus nonreturnable bottles. Of course, if the law is passed and the decision is to bottle the cola in nonreturnable bottles, all profits would be from out-of-state sales. Compute the expected profit for both bottling decisions. Which decision do you recommend?

Alternative	Law Is Passed (\$000), $S_1$	Law Is Not Passed (\$000), $S_2$
Returnable bottle	80	40
Nonreturnable bottle	25	60

LO20-3

Analyze a decision using opportunity loss.

Opportunity Loss

Another method to analyze a decision regarding which common stock to purchase is to determine the profit that might be lost because the state of nature (the market behavior) was not known at the time the investor bought the stock. This potential loss is called **opportunity loss** or **regret**. To illustrate, suppose the investor had purchased the common stock of Rim Homes, and a bull market developed. Further, suppose the value of his Rim Homes stock increased from \$1,100 to \$2,200, as anticipated. But had the investor bought Kayser Chemicals stock and market values increased, the value of his Kayser stock would be \$2,400 (from Table 20–1). Thus, the investor missed making an extra profit of \$200 by buying Rim Homes instead of Kayser Chemicals. To put it another way, the \$200 represents the opportunity loss for not knowing the future state of nature. If market prices did increase, the investor would have *regretted* buying Rim Homes. However, had the investor bought Kayser Chemicals and market prices increased, he would have had no regret, that is, no opportunity loss.

The opportunity losses corresponding to this example are given in Table 20–4. Each amount is the outcome (opportunity loss) of a particular combination of acts and a state of nature, that is, stock purchase and market reaction.

TABLE 20–4 Opportunity Losses for Various Combinations of Stock Purchase and Market Movement

Purchase	Opportunity Loss	
	Market Rise	Market Decline
Kayser Chemicals	\$ 0	\$150
Rim Homes	200	50
Texas Electronics	500	0

Notice that the stock of Kayser Chemicals would be a good investment choice in a rising (bull) market, Texas Electronics would be the best buy in a declining (bear) market, and Rim Homes is somewhat of a compromise.

SELF-REVIEW 20–2



- Refer to Table 20–4. Verify that the opportunity loss for:
- (a) Rim Homes, given a market decline, is \$50.
  - (b) Texas Electronics, given a market rise, is \$500.

## EXERCISES

3. Refer to Exercise 1. Develop an opportunity loss table. Determine the opportunity loss for each decision.
4. Refer to Exercise 2, involving Wilhelms Cola Company. Develop an opportunity loss table, and determine the opportunity loss for each decision.

### Expected Opportunity Loss

The opportunity losses in Table 20–4 again ignore the historical experience of market movements. Recall that the probability of a market rise is .60 and that of a market decline .40. These probabilities and the opportunity losses can be combined to determine the **expected opportunity loss**. These calculations are shown in Table 20–5 for the decision to purchase Rim Homes. The expected opportunity loss is \$140.

**TABLE 20–5** Expected Opportunity Loss for the Act of Buying Rim Homes Stock

State of Nature	Opportunity Loss	Probability of State of Nature	Expected Opportunity Loss
Market rise, $S_1$	\$200	.60	\$120
Market decline, $S_2$	50	.40	20
			<u>\$140</u>

Interpreting, the expected opportunity loss of \$140 means that, in the long run, the investor would lose the opportunity to make an additional profit of \$140 if he decided to buy Rim Homes stock. This expected loss would be incurred because the investor was unable to accurately predict the trend of the stock market. In a bull market, he could earn an additional \$200 by purchasing the common stock of Kayser Chemicals, but in a bear market an investor could earn an additional \$50 by buying Texas Electronics stock. When weighted by the probability of the event, the expected opportunity loss is \$140.

These calculations are summarized as follows:

<b>EXPECTED OPPORTUNITY LOSS</b>	$EOL(A_i) = \sum [P(S_j) \cdot R(A_i, S_j)]$	<b>(20–2)</b>
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where:

- $EOL(A_i)$  refers to the expected opportunity loss for a particular decision alternative.
- $P(S_j)$  refers to the probability associated with the states of nature  $j$ .
- $R(A_i, S_j)$  refers to the regret or loss for a particular combination of a state of nature and a decision alternative.

$EOL(A_2)$ , the regret, or expected opportunity loss, for selecting Rim Homes, is computed as follows:

$$\begin{aligned}
 EOL(A_2) &= [P(S_1) \cdot R(A_2, S_1)] + [P(S_2) \cdot R(A_2, S_2)] \\
 &= .60(\$200) + .40(\$50) = \$140
 \end{aligned}$$

The expected opportunity losses for the three decision alternatives are given in Table 20–6. The lowest expected opportunity loss is \$60, meaning that the investor would experience the least regret on average if he purchased Kayser Chemicals.

**TABLE 20–6** Expected Opportunity Losses for the Three Stocks

Purchase	Expected Opportunity Loss
Kayser Chemicals	\$ 60
Rim Homes	140
Texas Electronics	300

Incidentally, note that the decision to purchase Kayser Chemicals stock because it offers the lowest expected opportunity loss reinforces the decision made previously, that Kayser stock would ultimately result in the highest expected payoff (\$1,840). These two approaches (lowest expected opportunity loss and highest expected payoff) will always lead to the same decision concerning which course of action to follow.

## SELF-REVIEW 20–3



Referring to Table 20–6, verify that the expected opportunity loss for the act of purchasing Texas Electronics is \$300.

## EXERCISES

- Refer to Exercises 1 and 3. Compute the expected opportunity losses.
- Refer to Exercises 2 and 4. Compute the expected opportunity losses.

### LO20-4

Apply maximin, maximax, and minimax regret strategies to make a decision.

## Maximin, Maximax, and Minimax Regret Strategies

Suppose several financial advisors believe the decision to purchase Kayser Chemicals stock is too risky. They note that the payoff might not be \$1,840, but only \$1,000 (from Table 20–1). Arguing that the stock market is too unpredictable, they urge the investor to take a more conservative position and buy Texas Electronics. This is called a **maximin strategy**: it maximizes the minimum gain. On the basis of the payoff table (Table 20–1), they reason that the investor would be assured a profit of at least \$1,150. Those who subscribe to this somewhat pessimistic strategy are sometimes called **maximiners**.

At the other extreme are the optimistic **maximaxers**, who would select the stock that maximizes the maximum gain. If their **maximax strategy** was followed, the investor would purchase Kayser Chemicals stock. These optimists stress that there is a possibility of selling the stock in the future for \$2,400 instead of only \$1,150, as advocated by the maximiners.

Another strategy is the **minimax regret strategy**. Advisors advocating this approach would scan the opportunity losses in Table 20–4 and select the stock that minimizes the maximum regret. In this example, it would be Kayser Chemicals stock, with a maximum opportunity loss of \$150. Recall that you wish to *avoid* opportunity losses! The maximum regrets were \$200 for Rim Homes and \$500 for Texas Electronics.



**LO20-5**

Compute and explain the expected value of perfect information.

## Value of Perfect Information

Before deciding on a stock, the investor might want to consider ways of predicting the movement of the stock market. If he knew precisely what the market would do, he could maximize profit by always purchasing the correct stock. The question is: What is this advance information worth? The dollar value of this information is called the **expected value of perfect information**, written EVPI. In this example, if perfect information is available, Bob Hill would know what will happen in the future and whether the stock market will rise or decline. If Bob had this information, he would always make the best decision. The question is: What is the most that Bob should be willing to pay for perfect information?

An acquaintance who is an analyst with a large brokerage firm said that he would be willing to supply Bob with information that he might find valuable in predicting market rises and declines. Of course, there would be a fee, as yet undetermined, for this information, regardless of whether the investor used it. What is the maximum amount that Bob should pay for this special service? \$10? \$100? \$500?

The value of the information from the analyst is, in essence, the expected value of perfect information because the investor would then be assured of buying the most profitable stock.

**VALUE OF PERFECT INFORMATION** The difference between the maximum expected payoff under conditions of certainty and the maximum expected payoff under uncertainty.

In this example, it is the difference between the maximum value of the stock at the end of the year under conditions of certainty and the value associated with the optimum decision using the expected-value criterion.

To explain, the maximum expected value under conditions of certainty means that the investor would buy Kayser Chemicals if a market rise were predicted and Texas Electronics if a market decline were imminent. The expected payoff under conditions of certainty is \$1,900. (See Table 20–7.)

**TABLE 20–7** Calculations for the Expected Payoff under Conditions of Certainty

State of Nature	Decision	Payoff	Probability of State of Nature	Expected Payoff
Market rise, $S_1$	Buy Kayser	\$2,400	.60	\$1,440
Market decline, $S_2$	Buy Texas Electronics	1,150	.40	460
				<u>\$1,900</u>

Recall that if the actual behavior of the stock market was unknown (conditions of uncertainty), the stock to buy would be Kayser Chemicals; its expected value at the end of the period was computed to be \$1,840 (from Table 20–3). The value of perfect information is, therefore, \$60, found by:

\$1,900	Expected value of stock purchased under conditions of certainty
<u>–1,840</u>	Expected value of purchase (Kayser) under conditions of uncertainty
\$ 60	Expected value of perfect information

In general, the expected value of perfect information is computed as follows:

### EXPECTED VALUE OF PERFECT INFORMATION

$$\text{EVPI} = \text{Expected value under conditions of certainty} - \text{Expected value under conditions of uncertainty} \quad (20-3)$$

It would be worth up to \$60 for the information the stock analyst might supply. In essence, the analyst would be “guaranteeing” a selling price on average of \$1,900, and if the analyst asked \$40 for the information, the investor would be assured of a \$1,860 payoff, found by  $\$1,900 - \$40$ . Thus, it would be worthwhile for the investor to agree to this fee (\$40) because the expected outcome (\$1,860) would be greater than the expected value under conditions of uncertainty (\$1,840). However, if his acquaintance wanted a fee of \$100 for the service, the investor would realize only \$1,800 on average, found by  $\$1,900 - \$100$ . Logically, the service would not be worth \$100 because the investor could expect \$1,840 on average without agreeing to this financial arrangement. Notice that the expected value of perfect information (\$60) is the same as the minimum of the expected regrets (Table 20–6). That is not an accident.

Payoff Table			
Purchase	Bull Market	Bear Market	Expected Value
Kayser	\$2,400	\$1,000	\$1,840
Rim	2,200	1,100	1,760
Texas	1,900	1,150	1,600
Opportunity Loss Table			
Purchase	Bull Market	Bear Market	Expected Value
Kayser	\$ 0	\$ 150	\$ 60
Rim	200	50	140
Texas	500	1,150	760

The expected payoff and the expected opportunity loss are the same as reported in Table 20–3 and Table 20–6, respectively. The calculations in the preceding investment example were kept at a minimum to emphasize the new terms and the decision-making procedures. When the number of decision alternatives and the number of states of nature become large, a computer package or spreadsheet is recommended.

#### LO20-6

Apply sensitivity analysis to evaluate a decision subject to uncertainty.

## Sensitivity Analysis

In the foregoing stock selection situation, the set of probabilities applied to the payoff values was derived from historical experience with similar market conditions. Objections may be voiced, however, that future market behavior may be different from past experiences. Despite these differences, *the rankings of the decision alternatives are frequently not highly sensitive to changes within a plausible range*. As an example, suppose the investor’s brother believes that instead of a 60% chance of a market rise and a 40% chance of a decline, the reverse is true—that is, there is a .40 probability that the stock market will rise and a .60 probability of a decline. Further, the investor’s cousin thinks the probability of a market rise is .50 and that of a decline is .50. A comparison of the original expected payoffs (left column), the expected payoffs for the set of probabilities suggested by the investor’s brother (center column), and those cited by the cousin (right column) is shown in Table 20–8. The decision is the same in all three cases—purchase Kayser Chemicals.

**TABLE 20–8** Expected Payoffs for Three Sets of Probabilities

Purchase	Expected Payoffs		
	Historical Experience (probability of .60 rise, .40 decline)	Brother's Estimate (probability of .40 rise, .60 decline)	Cousin's Estimate (probability of .50 rise, .50 decline)
Kayser Chemicals	\$1,840	\$1,560	\$1,700
Rim Homes	1,760	1,540	1,650
Texas Electronics	1,600	1,450	1,525

## SELF-REVIEW 20–4



Referring to Table 20–8, verify that:

- The expected payoff for Texas Electronics for the brother's set of probabilities is \$1,450.
- The expected payoff for Kayser Chemicals for the cousin's set of probabilities is \$1,700.

A comparison of the three sets of expected payoffs in Table 20–8 reveals the best alternative would still be to purchase Kayser Chemicals. As might be expected, there are some differences in the expected future values for each of the three stocks.

If there are drastic changes in the assigned probabilities, the expected values and the optimal decision may change. As an example, suppose the likelihood of a market rise was .20 and for a market decline .80. The expected payoffs would be as shown in Table 20–9. In the long run, the best alternative would be to buy Rim Homes stock. Thus, sensitivity analysis lets you see how accurate the probability estimates need to be in order to feel comfortable with your choice.

**TABLE 20–9** Expected Values for Purchasing the Three Stocks

Purchase	Expected Payoff
Kayser Chemicals	\$1,280
Rim Homes	1,320
Texas Electronics	1,300

## SELF-REVIEW 20–5



Is there any choice of probabilities for which the best alternative would be to purchase Texas Electronics stock? (Hint: This can be arrived at algebraically or by using a trial-and-error method. Try a somewhat extreme probability for a market rise.)

## EXERCISES

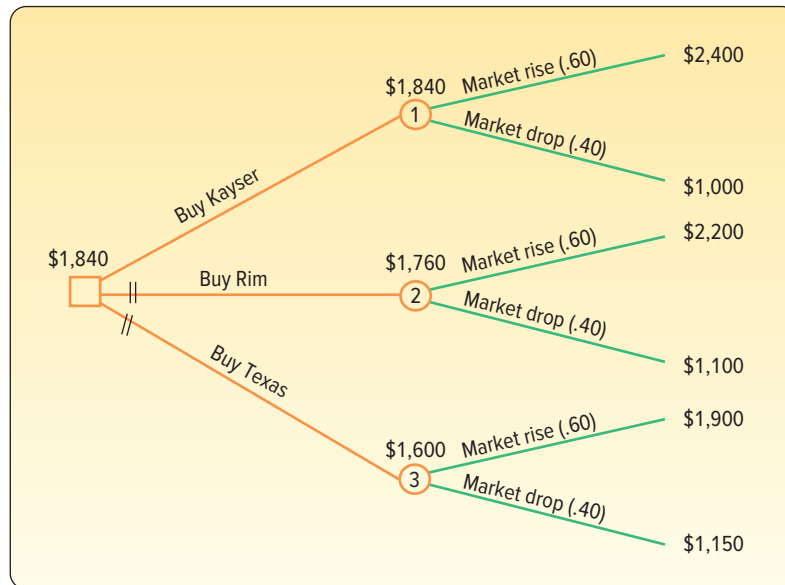
- Refer to Exercises 1, 3, and 5. Compute the expected value of perfect information.
- Refer to Exercises 2, 4, and 6. Compute the expected value of perfect information.
- Refer to Exercise 1. Revise the probabilities as follows:  $P(S_1) = .50$ ,  $P(S_2) = .20$ , and  $P(S_3) = .30$  and use Expected Monetary Value to evaluate the decision. Does this change the decision?
- Refer to Exercise 2. Reverse the probabilities; that is, let  $P(S_1) = .30$  and  $P(S_2) = .70$  and use Expected Monetary Value to evaluate the decision. Does this alter your decision?

**LO20-7**

Use a decision tree to illustrate and analyze decision making under uncertainty.

## Decision Trees

An analytic tool introduced in Chapter 5 that is also useful for studying a decision situation is a **decision tree**. It is a picture of all the possible courses of action and the consequent possible outcomes. A box is used to indicate the point at which a decision must be made, and the branches going out from the box indicate the alternatives under consideration. Referring to Chart 20–1, on the left is the box with three branches radiating from it, representing the acts of purchasing Kayser Chemicals, Rim Homes, or Texas Electronics.



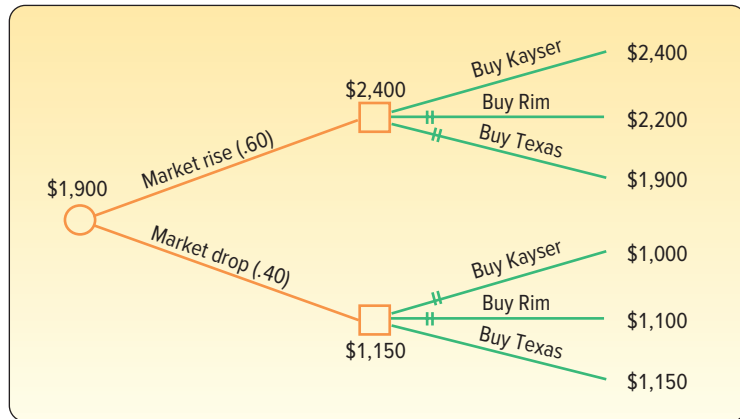
**CHART 20–1** Decision Tree for the Investor's Decision

The three nodes, or circles, numbered 1, 2, and 3, represent the expected payoff of each of the three stocks. The branches going out to the right of the nodes show the chance events (market rise or decline) and their corresponding probabilities in parentheses. The numbers at the extreme ends of the branches are the estimated future values of ending the decision process at those points. This is sometimes called the *conditional payoff* to denote that the payoff depends on a particular choice of action and a particular chance outcome. Thus, if the investor purchased Rim Homes stock and the market rose, the conditional value of the stock would be \$2,200.

After the decision tree has been constructed, the best decision strategy is found by what is termed *backward induction*. For example, suppose the investor is considering the act of purchasing Texas Electronics. Starting at the lower right in Chart 20–1 with the anticipated payoff given a market rise (\$1,900) versus a market decline (\$1,150) and going backward (moving left), the appropriate probabilities are applied to give the expected payoff of \$1,600 [found by  $.60(\$1,900) + .40(\$1,150)$ ]. The investor would mark the expected value of \$1,600 above circled node 3 as shown in Chart 20–1. Similarly, the investor would determine the expected values for Rim Homes and Kayser Chemicals.

Assuming the investor wants to maximize the expected value of his stock purchase, \$1,840 would be preferred over \$1,760 or \$1,600. Continuing to the left toward the box, the investor would draw a double bar across branches representing the two alternatives he rejected (numbers 2 and 3, representing Rim Homes and Texas Electronics). The unmarked branch that leads to the box is clearly the best action to follow, namely, buy Kayser Chemicals stock.

The expected value under *conditions of certainty* can also be portrayed via a decision tree analysis (Chart 20–2). Recall that under conditions of certainty the investor would know *before the stock is purchased* whether the stock market would rise or decline. Hence, he would purchase Kayser Chemicals in a rising market and Texas Electronics in a falling market, and the expected payoff would be \$1,900. Again, backward induction would be used to arrive at the expected payoff of \$1,900.



**CHART 20–2** Decision Tree Given Perfect Information

The monetary difference based on perfect information in Chart 20–2 and the decision based on imperfect information in Chart 20–1 is \$60, found by  $\$1,900 - \$1,840$ . Recall that the \$60 is the expected value of perfect information.

Decision tree analysis provides an alternative method to perform the calculations presented earlier in the chapter. Some managers find these graphic sketches help them in following the decision logic.

## CHAPTER SUMMARY

- I. Statistical decision theory is concerned with making decisions from a set of alternatives.
  - A. The various courses of action are called the acts or alternatives.
  - B. The uncontrollable future events are called the states of nature. Probabilities are assigned to the states of nature.
  - C. The consequence of a particular decision alternative and state of nature is the payoff.
  - D. All possible combinations of decision alternatives and states of nature result in a payoff table.
- II. There are several criteria for selecting the best decision alternative.
  - A. The expected monetary value (EMV) computes the expected value for each decision. If the payoffs are costs, the decision with the smallest EMV is selected. If the payoffs are profits, the decision with the largest EMV is selected.
  - B. A decision can be selected using an opportunity loss table.
    1. To construct an opportunity loss table, first calculate the difference between the best payoff and the payoffs of the other decision alternatives for each state of nature.
    2. The difference between the optimal decision and any other decision is the opportunity loss or regret due to making a decision other than the optimum.
    3. The expected opportunity loss (EOL) is similar to the expected monetary value. The opportunity loss is combined with the probabilities of the various states of nature for each decision alternative to determine the expected opportunity loss.
  - C. A maximin strategy compares the lowest payoffs of the decision alternatives and selects the decision alternative with the maximum of these payoffs.



- D. A maximax strategy selects the decision alternative with the highest payoff.
- E. A minimax regret strategy, first, converts payoffs to regrets or opportunity losses. Then, decision alternatives are compared based on the maximum regrets and the alternative with the smallest of the maximum regrets is selected.
- III. The expected value of perfect information (EVPI) is the difference between the best expected payoff under certainty and the best expected payoff under uncertainty.
- IV. Sensitivity analysis examines the effects of various probabilities for the states of nature on the expected values.
- V. Decision trees are useful for structuring the various alternatives. They present a picture of the various courses of action and the possible states of nature.

## CHAPTER EXERCISES

11. Blackbeard's Phantom Fireworks is considering introducing two new bottle rockets. The company can add both to the current line, neither, or just one of the two. The success of these products depends on consumers' reactions. These reactions can be summarized as good,  $P(S_1) = .30$ ; fair,  $P(S_2) = .50$ ; or poor,  $P(S_3) = .20$ . The company's revenues, in thousands of dollars, are estimated in the following payoff table.

Decision	State of Nature		
	$S_1$	$S_2$	$S_3$
Neither	0	0	0
Product 1 only	125	65	30
Product 2 only	105	60	30
Both	220	110	40

- a. Compute the expected monetary value for each decision.
  - b. What decision would you recommend?
  - c. Develop an opportunity loss table.
  - d. Compute the expected opportunity loss for each decision.
  - e. Compute the expected value of perfect information.
12. A financial executive for Fidelity Investments lives in Boston but frequently must travel to New York. She can go to New York by car, train, or plane. The cost for a plane ticket from Boston to New York is \$200, and it is estimated that the trip takes 30 minutes in good weather and 45 minutes in bad weather. The cost for a train ticket is \$100, and the trip takes 1 hour in good weather and 2 hours in bad weather. The cost to drive her own car from Boston to New York is \$40, and this trip takes 3 hours in good weather and 4 in bad weather. The executive places a value of \$60 per hour on her time. The weather forecast is for a 60% chance of bad weather tomorrow. What decision would you recommend? (Hint: Set up a payoff table, and remember that you want to minimize costs.) What is the expected value of perfect information?
13. Thomas Manufacturing Company has \$100,000 available to invest. John Thomas, the president and CEO of the company, would like to either expand his production, invest the money in stocks, or purchase a certificate of deposit from the bank. Of course, the unknown is whether the economy will continue at a high level or there will be a recession. He estimates the likelihood of a recession at .20. Whether there is a recession or not, the certificate of deposit will result in a gain of 6%. If there is a recession, he predicts a 10% loss if he expands his production and a 5% loss if he invests in stocks. If there is not a recession, an expansion of production will result in a 15% gain, and stock investment will produce a 12% gain.
- a. What decision should he make if he uses the maximin strategy?
  - b. What decision should John Thomas make if the maximax strategy is used?
  - c. What decision would be made if he uses the expected monetary value criterion?
  - d. What is the expected value of perfect information?
14. The quality assurance department at Malcomb Products must either inspect each part in a lot or not inspect any of the parts. That is, there are two decision alternatives: Inspect

all the parts or inspect none of the parts. The proportion of parts defective in the lot,  $S_j$ , is known from historical data to assume the following probability distribution.

State of Nature, $S_j$	Probability, $P(S_j)$
.02	.70
.04	.20
.06	.10

For the decision not to inspect any parts, the cost of quality is  $C = NS_jK$ . For inspecting all the items in the lot, it is  $C = Nk$ , where:

$N = 20$  (lot size)

$K = \$18.00$  (the cost of finding a defect)

$k = \$0.50$  (the cost of sampling one item)

- a. Develop a payoff table.
  - b. What decision should be made if the expected value criterion is used?
  - c. What is the expected value of perfect information?
- 15.** Dude Ranches Incorporated was founded on the idea that many families in the eastern and southern areas of the United States do not have a sufficient amount of vacation time to drive to the dude ranches in the Southwest and Rocky Mountain areas for their vacations. Various surveys indicated, however, that there was a considerable interest in this type of family vacation, which includes horseback riding, cattle drives, swimming, fishing, and the like. Dude Ranches Incorporated bought a large farm near several eastern cities and constructed a lake, a swimming pool, and other facilities. However, to build a number of family cottages on the ranch would have required a considerable investment. Further, the owners reasoned that most of this investment would be lost should the ranch–farm complex be a financial failure. Instead, they decided to enter into an agreement with Mobile Homes Manufacturing Company to supply a very attractive authentic ranch-type mobile home. Mobile Homes agreed to deliver a mobile home on Saturday for \$300 a week. Mobile Homes must know early Saturday morning how many mobile homes Dude Ranches Incorporated wants for the forthcoming week. It has other customers to supply and can only deliver the homes on Saturday. This presents a problem. Dude Ranches will have some reservations by Saturday, but indications are that many families do not make them. Instead, they prefer to examine the facilities before making a decision. An analysis of the various costs involved indicated that \$350 a week should be charged for a ranch home, including all privileges. The basic problem is how many mobile ranch homes to order from Mobile Homes each week. Should Dude Ranches Incorporated order 10 (considered the minimum), 11, 12, 13, or 14 (considered the maximum)?

Any decision made solely on the information in the payoff table would ignore, however, the valuable experience that Dude Ranches Incorporated has acquired in the past 4 years (about 200 weeks) actually operating a dude ranch in the Southwest. Its records showed that it always had nine advance reservations. Also, it never had a demand for 15 or more cottages. The occupancy of 10, 11, 12, 13, or 14 ranch cottages, in part, represented families who drove in and inspected the facilities before renting. A frequency distribution showing the number of weeks in which 10, 11, . . . , 14 ranch cottages were rented during the 200-week period is found in the following table.

Number of Cottages Rented	Number of Weeks
10	26
11	50
12	60
13	44
14	20
	<u>200</u>

- a. Construct a payoff table.
  - b. Determine the expected payoffs, and arrive at a decision.
  - c. Set up an opportunity loss table.
  - d. Compute the expected opportunity losses, and arrive at a decision.
  - e. Determine the expected value of perfect information.
16. The proprietor of the newly built White Mountain Ski and Swim Lodge has been considering purchasing or leasing several snowmobiles for the use of guests. The owner found that other financial obligations made it impossible to purchase the machines. Snowmobiles Incorporated (SI) will lease a machine for \$20 a week, including any needed maintenance. According to SI, the usual rental charge to the guests of the lodge is \$25 a week. Gasoline and oil are extra. Snowmobiles Incorporated only leases a machine for the full season. The proprietor of Ski and Swim, knowing that leasing an excessive number of snowmobiles might cause a net loss for the lodge, investigated the records of other resort owners. The combined experience at several other lodges was found to be:

Number of Snowmobiles Demanded by Guests	Number of Weeks
7	10
8	25
9	45
10	20

- a. Design a payoff table.
  - b. Compute the expected profits for leasing 7, 8, 9, and 10 snowmobiles based on the cost of leasing of \$20, the rental charge of \$25, and the experience of other lodges.
  - c. Which alternative is the most profitable?
  - d. Design an opportunity loss table.
  - e. Find the expected opportunity losses for leasing 7, 8, 9, and 10 snowmobiles.
  - f. Which act would give the least expected opportunity loss?
  - g. Determine the expected value of perfect information.
  - h. Suggest a course of action to the proprietor of the Ski and Swim Lodge. Include in your explanation the various figures, such as expected profit.
17. Casual Furniture World has had numerous inquiries regarding the availability of furniture and equipment that could be rented for large outdoor summer parties. This includes such items as folding chairs and tables, a deluxe grill, propane gas, and lights. No rental equipment of this nature is available locally, and the management of the furniture store is considering forming a subsidiary to handle rentals.

An investigation revealed that most people interested in renting wanted a complete group of party essentials (about 12 chairs, four tables, a deluxe grill, a bottle of propane gas, tongs, etc.). Management decided not to buy a large number of complete sets because of the financial risk involved. That is, if the demand for the rental groups was not as large as anticipated, a large financial loss might be incurred. Further, outright purchase would mean that the equipment would have to be stored during the off-season.

It was then discovered that a firm in Boston leased a complete party set for \$560 for the summer season. This amounts to about \$5 a day. In the promotional literature from the Boston firm, a rental fee of \$15 was suggested. For each set rented, a profit of \$10 would thus be earned. It was then decided to lease from the Boston firm, at least for the first season.

The Boston firm suggested that, based on the combined experience of similar rental firms in other cities, either 41, 42, 43, 44, 45, or 46 complete sets be leased for the season. Based on this suggestion, management must now decide on the most profitable number of complete sets to lease for the season.

The leasing firm in Boston also made available some additional information gathered from several rental firms similar to the newly formed subsidiary. Note in the following table (which is based on the experience of the other rental firms) that for 360 days of

the total of 6,000 days' experience—or about 6% of the days—these rental firms rented out 41 complete party sets. On 10% of the days during a typical summer, they rented 42 complete sets, and so on.

Number of Sets Rented	Number of Days
40	0
41	360
42	600
43	840
44	2,400
45	1,500
46	300
47	0

- a. Construct a payoff table. (As a check figure, for the act of having 41 complete sets available and the event of renting 41, the payoff is \$410.)
  - b. The expected daily profit for leasing 43 complete sets from the Boston firm is \$426.70; for 45 sets, \$431.70; and for 46 sets, \$427.45. Organize these expected daily profits into a table, and complete the table by finding the expected daily profit for leasing 41, 42, and 44 sets from the Boston firm.
  - c. On the basis of the expected daily profit, what is the most profitable action to take?
  - d. The expected opportunity loss for leasing 43 party sets from the Boston firm is \$11.60; for 45 sets, \$6.60; for 46 sets, \$10.85. Organize these into an expected opportunity loss table, and complete the table by computing the expected opportunity loss for 41, 42, and 44.
  - e. According to the expected opportunity loss table, what is the most profitable course of action to take? Does this agree with your decision for part (c)?
  - f. Determine the expected value of perfect information. Explain what it indicates in this problem.
18. Tim Waltzer owns and operates Waltzer's Wrecks, a discount car rental agency near Cleveland Hopkins International Airport. He rents a wreck for \$20 a day. He has an arrangement with Landrum Leasing to purchase used cars at \$6,000 each. His cars receive only needed maintenance and, as a result, are worth only \$2,000 at the end of the year of operation. Tim has decided to sell all his wrecks every year and purchase a complete set of wrecks from Landrum Leasing.

His clerk-accountant provided him with a probability distribution with respect to the number of cars rented per day.

	Numbers of Cars Rented per Day			
	20	21	22	23
Probability	.10	.20	.50	.20

Tim is an avid golfer and tennis player. He is either on the golf course on weekends or playing tennis indoors. Thus, his car rental agency is only open weekdays. Also, he closes for 2 weeks during the summer and goes on a golfing tour.

The clerk-accountant estimated that it cost \$1.50 per car rental for minimal maintenance and cleaning.

- a. How many cars should he purchase to maximize profit?
  - b. What is the expected value of perfect information?
19. You sign up for a cell phone plan and are presented with this chart showing how your plan "automatically adjusts" to the minutes you use each month. For example: If you select Option 1 and you use 700 minutes the first month, you'll only pay \$79.99. If your usage then goes down to 200 minutes the second month, you'll only pay \$29.99. You guess your monthly usage will be 100, 300, 500, or 700 anytime minutes. Assume the probabilities for each event are the same.

Option 1—Starting at \$29.99 per Month	
Anytime Minutes	Cost
0–200	\$29.99
201–700	\$5 for each 50 minutes
Above 700	Additional anytime minutes only 10¢ each
Option 2—Starting at \$34.99 per Month	
Anytime Minutes	Cost
0–400	\$34.99
401–900	\$5 for each 50 minutes
Above 900	Additional anytime minutes only 10¢ each
Option 3—Starting at \$59.99 per Month	
Anytime Minutes	Cost
0–1,000	\$59.99
1,001–1,500	\$5 for each 50 minutes
Above 1,500	Additional anytime minutes only 10¢ each

- Create a payoff (cost) table for this decision.
  - Using the expected monetary value principle, which decision would you suggest?
  - Using the optimistic (maximax cost) approach, which decision would you suggest?
  - Using the pessimistic (maximin cost) strategy, which decision would you suggest?
  - Work out an opportunity loss table for this decision.
  - Using the minimax regret strategy, which choice would you suggest?
  - What is the expected value of perfect information?
20. You're about to drive to New York. If your car's engine is out of tune, your gas cost will increase by \$100. Having the engine tested will cost \$20. If it's out of tune, repairs will cost \$60. Before testing, the probability is 30% that the engine is out of tune. What should you do?