The expected number of weeks for each activity in our example is shown in parentheses along each path in Figure A.5. The critical path—or the longest path through the PERT network—is then identified. This path is considered critical because it shows the shortest time in which the project can be completed. In our example, the critical path is 1-2-3-6-7-9-10-11-12-13, totaling fifty-seven weeks. PERT thus tells the manager that the project will take fifty-seven weeks to complete.

The first network may be refined. If fifty-seven weeks to completion is too long a time, the manager might decide to begin preliminary package design before the test products are finished. Or the manager might decide that ten weeks rather than twelve is a sufficient time period to monitor sales. The idea is that if the critical path can be shortened, so too can the overall duration of the project. The PERT network serves as an ongoing framework for both planning and control throughout the project. For example, the manager can use it to monitor where the project is relative to where it needs to be. Thus, if an activity on the critical path takes longer than planned, the manager needs to make up the time elsewhere or live with the fact that the entire project will be late.

Decision-Making Tools

Managers can also use a number of tools that relate more specifically to decision making than to planning. Two commonly used decision-making tools are payoff matrices and decision trees.

Payoff Matrices

A payoff matrix specifies the probable value of different alternatives, depending on different possible outcomes associated with each. The use of a payoff matrix requires that several alternatives be available, that several different events could occur, and that the consequences depend on which alternative is selected and on which event or set of events occurs. An important concept in understanding the payoff matrix, then, is probability. A probability is the likelihood, expressed as a percentage, that a particular event will or will not occur. If we believe that a particular event will occur seventy-five times out of one hundred, we can say that the probability of its occurring is 75 percent, or .75. Probabilities range in value from 0 (no chance of occurrence) to 1.00 (certain occurrence—also referred to as 100 percent). In the business world, there are few probabilities of either 0 or 1.00. Most probabilities that managers use are based on subjective judgment, intuition, and historical data.

The expected value of an alternative course of action is the sum of all possible values of outcomes from that action multiplied by their respective probabilities. Suppose, for example, that a venture capitalist is considering investing in a new company. If he believes there is a .40 probability of making $100,000, a .30 probability of making $50,000, and a .30 probability of losing $100,000, then the expected value of making the investment is $20,000. It would be a good idea to look for another investment opportunity.
making $30,000, and a .30 probability of losing $20,000, the expected value (EV) of this alternative is

\[
EV = .40(100,000) + .30(-30,000) + .30(-20,000)
\]

\[
EV = 40,000 - 9,000 - 6,000
\]

\[
EV = 43,000
\]

The investor can then weigh the expected value of this investment against the expected values of other available alternatives. The highest EV signals the investment that should most likely be selected.

For example, suppose another venture capitalist wants to invest $20,000 in a new business. She has identified three possible alternatives: a leisure products company, an energy enhancement company, and a food-producing company. Because the expected value of each alternative depends on short-run changes in the economy, especially inflation, she decides to develop a payoff matrix. She estimates that the probability of high inflation is .30 and the probability of low inflation is .70. She then estimates the probable returns for each investment in the event of both high and low inflation. Figure A.6 shows what the payoff matrix might look like (a minus sign indicates a loss). The expected value of investing in the leisure products company is

\[
EV = .30(-10,000) + .70(50,000)
\]

\[
EV = -3,000 + 35,000
\]

\[
EV = 32,000
\]

Similarly, the expected value of investing in the energy enhancement company is

\[
EV = .30(90,000) + .70(-15,000)
\]

\[
EV = 27,000 + (-10,500)
\]

\[
EV = 16,500
\]
And, finally, the expected value of investing in the food-processing company is

\[ EV = 0.30(30,000) + 0.70(25,000) \]
\[ EV = 9,000 + 17,500 \]
\[ EV = 26,500 \]

Investing in the leisure products company, then, has the highest expected value.

Other potential uses for payoff matrices include determining optimal order quantities, deciding whether to repair or replace broken machinery, and deciding which of several new products to introduce. Of course, the real key to using payoff matrices effectively is making accurate estimates of the relevant probabilities.

**Decision Trees**

Decision trees are like payoff matrices because they enhance a manager’s ability to evaluate alternatives by making use of expected values. However, they are most appropriate when there are several decisions to be made in sequence.

Figure A.7 illustrates a hypothetical decision tree. The small firm represented wants to begin exporting its products to a foreign market, but limited capacity restricts it to only one market at first. Managers feel that either France or China would be the best place to start. Whichever alternative is selected, sales for the product in that country may turn out to be high or low. In France, there is a .80 chance of high sales and a .20 chance of low sales. The anticipated payoffs in these situations are predicted to be $20 million and $3 million, respectively. In China, the probabilities of high versus low sales are .60 and .40, respectively, and the associated payoffs are presumed to be $25 million and $6 million. As shown in Figure A.7, the expected value of shipping to France is $16,600,000, whereas the expected value of shipping to China is $17,400,000.

The astute reader will note that this part of the decision could have been set up as a payoff matrix. However, the value of decision trees is that we can extend the model to include subsequent decisions. Assume, for example, that the company begins shipping to China. If high sales do in fact materialize, the company will soon reach another decision situation. It might use the extra revenues to (1) increase shipments to China, (2) build a plant close to China and thus cut shipping costs, or (3) begin shipping to France. Various outcomes are possible for each decision, and each outcome will also have both a probability and an anticipated payoff. It is therefore possible to compute expected values back through several tiers of decisions all the way to the initial one. As it is with payoff matrices, determining probabilities accurately is the crucial element in the process. Properly used, however, decision trees can provide managers with a useful road map through complex decision situations.

**Other Techniques**

In addition to payoff matrices and decision trees, several other quantitative methods are also available to facilitate decision making.
Inventory models are techniques that help the manager decide how much inventory to maintain. Target Stores uses inventory models to help determine how much merchandise to order, when to order it, and so forth. Inventory consists of both raw materials (inputs) and finished goods (outputs). Polaroid, for example, maintains a supply of the chemicals that it uses to make film, the cartons it packs film in, and packaged film ready to be shipped. For finished goods, both extremes are bad: excess inventory ties up capital, whereas a small inventory may result in shortages and customer dissatisfaction. The same holds for raw materials: too much inventory ties up capital, but if a company runs out of resources, work stoppages may occur. Finally, because the process of placing an order for raw materials and supplies has associated costs (such as clerical time, shipping expenses, and higher unit costs for small quantities), it is important to minimize the frequency of

**Figure A.7**  
An Example of a Decision Tree
A decision tree extends the basic concepts of a payoff matrix through multiple decisions. This tree shows the possible outcomes of two levels of decisions. The first decision is whether to expand to China or to France. The second decision, assuming that the company expands to China, is whether to increase shipments to China, build a plant close to China, or initiate shipping to France.
ordering. Inventory models help the manager make decisions that optimize the size of inventory. New innovations in inventory management such as just-in-time, or JIT, rely heavily on decision-making models. A JIT system involves scheduling materials to arrive in small batches as they are needed, thereby eliminating the need for a big reserve inventory, warehouse space, and so forth.6

**Queuing Models** Queuing models are intended to help organizations manage waiting lines. We are all familiar with such situations: shoppers waiting to pay for groceries at Kroger, drivers waiting to buy gas at an Exxon station, travelers calling American Airlines for reservations, and customers waiting for a teller at Citibank. Take the Kroger example. If a store manager has only one check-out stand in operation, the store’s cost for check-out personnel is very low; however, many customers are upset by the long line that frequently develops. To solve the problem, the store manager could decide to keep twenty check-out stands open at all times. Customers would like the short waiting period, but personnel costs would be very high. A queuing model would be appropriate in this case to help the manager determine the optimal number of check-out stands: the number that would balance personnel costs and customer waiting time. Target Stores uses queuing models to determine how many check-out lanes to put in its retail stores.

**Distribution Models** A decision facing many marketing managers relates to the distribution of the organization’s products. Specifically, the manager must decide where the products should go and how to transport them. Railroads, trucking, and air freight have associated shipping costs, and each mode of transportation follows different schedules and routes. The problem is to identify the combination of routes that optimize distribution effectiveness and distribution costs. Distribution models help managers determine this optimal pattern of distribution.

**Game Theory** Game theory was originally developed to predict the effect of one company’s decisions on competitors. Models developed from game theory are intended to predict how a competitor will react to various activities that an organization might undertake, such as price changes, promotional changes, and the introduction of new products. If Wells Fargo Bank were considering raising its prime lending rate by 1 percent, it might use a game theory model to predict whether Citicorp would follow suit. If the model revealed that Citicorp would do so, Wells Fargo would probably proceed; otherwise, it would probably maintain the current interest rates. Unfortunately, game theory is not yet as useful as it was originally expected to be. The complexities of the real world combined with the limitation of the technique itself restrict its applicability. Game theory, however, does provide a useful conceptual framework for analyzing competitive behavior, and its usefulness may be improved in the future.

**Artificial Intelligence** A fairly new addition to the manager’s quantitative tool kit is artificial intelligence (AI). The most useful form of AI is the expert system.7 An expert system is essentially a computer program that attempts to duplicate the thought processes of experienced decision makers. For example, Hewlett-Packard
has developed an expert system that checks sales orders for new computer systems and then designs preliminary layouts for those new systems. HP can now ship the computer to a customer in components for final assembly on site. This approach has enabled the company to cut back on its own final-assembly facilities.

**Strengths and Weaknesses of Planning Tools**

Like all issues confronting management, planning tools of the type described here have several strengths and weaknesses.

**Weaknesses and Problems**

One weakness of the planning and decision-making tools discussed in this appendix is that they may not always adequately reflect reality. Even with the most sophisticated and powerful computer-assisted technique, reality must often be simplified. Many problems are also not amenable to quantitative analysis because important elements of them are intangible or nonquantifiable. Employee morale or satisfaction, for example, is often a major factor in managerial decisions.

The use of these tools and techniques may also be quite costly. For example, only larger companies can afford to develop their own econometric models. Even though the computer explosion has increased the availability of quantitative aids, some expense is still involved and it will take time for many of these techniques to become widely used. Resistance to change also limits the use of planning tools in some settings. If a manager for a retail chain has always based decisions for new locations on personal visits, observations, and intuition, she or he may be less than eager to begin using a computer-based model for evaluating and selecting sites. Finally, problems may arise when managers have to rely on technical specialists to use sophisticated models. Experts trained in the use of complex mathematical procedures may not understand or appreciate other aspects of management.

**Strengths and Advantages**

On the plus side, planning and decision-making tools offer many advantages. For situations that are amenable to quantification, they can bring sophisticated mathematical processes to bear on planning and decision making. Properly designed models and formulas also help decision makers “see reason.” For example, a manager might not be inclined to introduce a new product line simply because she or he doesn’t think it will be profitable. After seeing a forecast predicting first-year sales of one hundred thousand units coupled with a breakeven analysis showing profitability after only twenty thousand, however, the manager will probably change her or his mind. Thus, rational planning tools and techniques force the manager to look beyond personal prejudices and predispositions. Finally, the computer explosion is rapidly making sophisticated planning techniques available in a wider range of settings than ever before.