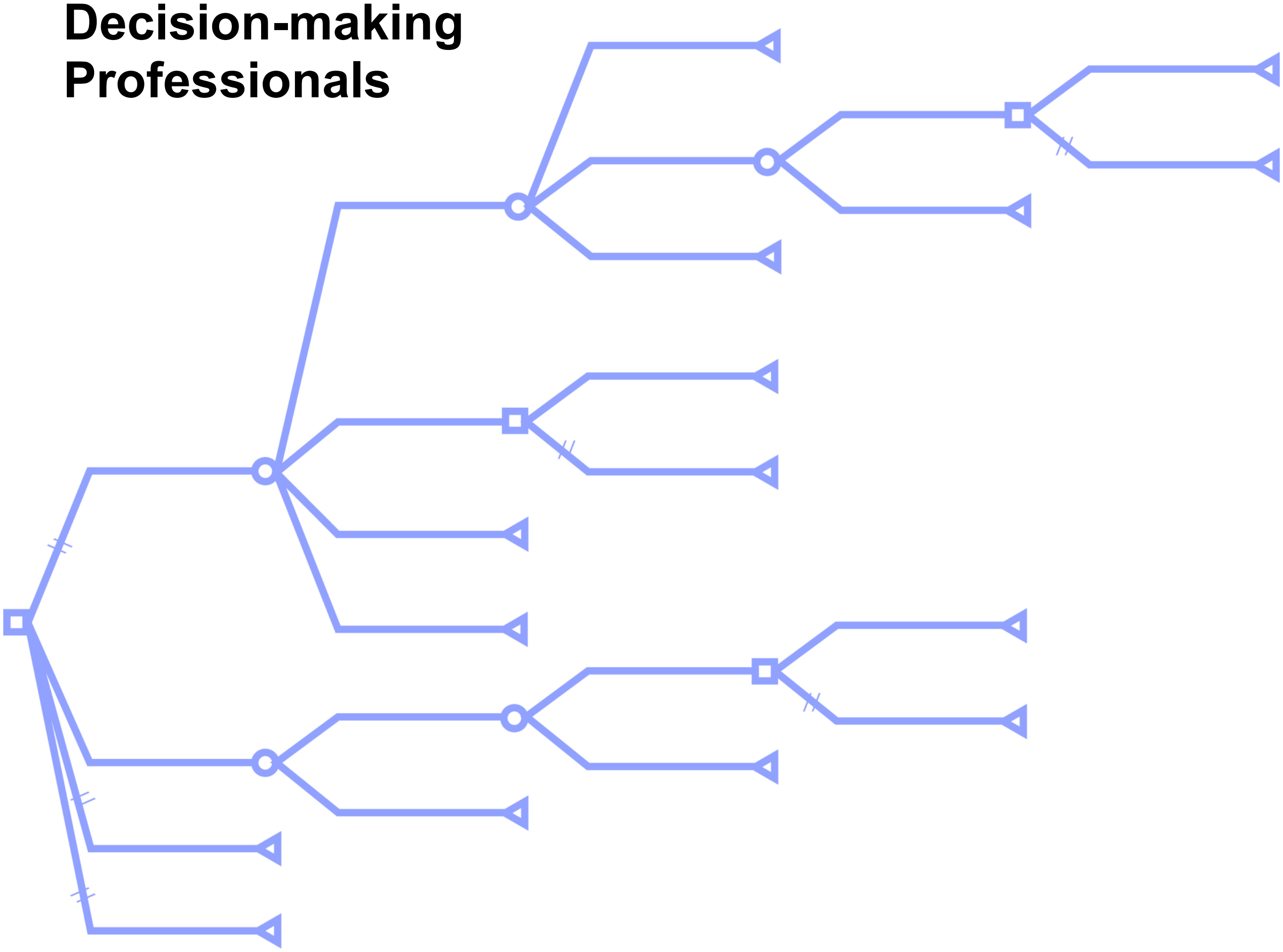
Decision Trees

A Primer for Decision-making Professionals



By Rafael Olivas
2007

Table of Contents

Preface

Decision trees find use in a wide range of disparate applications. They are used in many different disciplines including medical diagnosis, cognitive science, artificial intelligence, game theory, engineering, and data mining. Despite this trend surprisingly few good, clear introductions to basic decision tree concepts are available. The present work attempts to meet that need by offering a concise primer for novices.

Acknowledgments

The author gratefully acknowledges instructor Meryl Natches, CEO of TechProse, for invaluable editing, guidance, and patience. The author also thanks the Technical Communication 1 class participants at UC Berkeley Extension during the spring semester 2007 for review and comments.

Rosana Francescato tested the material for clarity and provided helpful feedback in the development of this project.

CJ Kalin, Ph.D., introduced me to the decision tree method in a Project Risk Management class at UC Berkeley Extension. Her real-world examples demonstrated how the decision trees technique helps solve complex project management problems.

Despite the aforementioned contributions the author accepts responsibility for any errors or omissions herein.

Please send feedback to rafael@projectsphinx.com

Rev. 5, 04/05/07

1.0 Introduction

A decision tree is a method you can use to help make good choices, especially decisions that involve high costs and risks. Decision trees use a graphic approach to compare competing alternatives and assign values to those alternatives by combining uncertainties, costs, and payoffs into specific numerical values.

If you are a project manager, business analyst, or a project decision-maker, this primer is for you. If you are interested in cognitive science, artificial intelligence, data mining, medical diagnosis, formal problem solving, or game theory, this primer provides an introduction to basic concepts of decision tree analysis.

1.1 Advantages of using decision trees

Decision trees offer advantages over other methods of analyzing alternatives. They are:

- **Graphic**. You can represent decision alternatives, possible outcomes, and chance events schematically. The visual approach is particularly helpful in comprehending sequential decisions and outcome dependencies.
- **Efficient**. You can quickly express complex alternatives clearly. You can easily modify a decision tree as new information becomes available. Set up a decision tree to compare how changing input values affect various decision alternatives. Standard decision tree notation is easy to adopt.
- **Revealing**. You can compare competing alternatives—even without complete information—in terms of risk and probable value. The Expected Value (EV) term combines relative investment costs, anticipated payoffs, and uncertainties into a single numerical value. The EV reveals the overall merits of competing alternatives.
- **Complementary**. You can use decision trees in conjunction with other project management tools. For example, the decision tree method can help evaluate project schedules.

1.2 About this primer

This primer offers an introduction to basic decision tree analysis. After studying this material for an hour, most users will be able to understand and apply decision tree analysis to solve simple and even moderately complex decision problems.

You can readily construct and analyze simple decision trees such as those found in this primer with pen, paper, and a calculator. However, a spreadsheet such as Microsoft Excel can dramatically facilitate setting up and modifying decision trees. A number of other software applications are also available. These range from low-cost Microsoft Excel plug-ins to more expensive dedicated applications. For the purposes of this primer, a pen, paper, and calculator are sufficient.

1.3 To use this primer

You can use this primer in several ways. If you prefer to get started immediately with drawing and using decision tree notation, then begin with the **Decision Scenario**, an exercise that puts you in the role of using a decision tree in step-by-step fashion. If you are more comfortable learning by first seeing how a process works, then start with **Basic Concepts**. Whichever way you begin, make sure to review both of these sections. The **Glossary** defines underlined terms. After you review the concepts and use the scenario exercise, you can find external references in **More to Explore**.

Icons indicate items of special interest:

- Example
- Exercise
- Note
- Tip

2.0 Decision Scenario

Consider the following scenario. Really Big Ideas, Inc., a small company that develops inventions for the consumer market, has recruited you as a consultant to make a recommendation on a critical business decision. At 10:00 a.m., you meet Adam Smith, the Vice President in charge of product development. Smith expresses his wish for an outside opinion on a decision the company must make soon. Your job is to supply such an informed opinion.

Smith tells you that a short meeting will provide all the information needed and introduce the project managers for two possible (and competing) products. As Smith ushers you into a conference room he also mentions that he expects your analysis by 11:00 a.m., scarcely an hour from now! You are given pen, paper, and a calculator.

At 10:05 a.m., you and Smith enter a small meeting room. Smith explains that Really Big Ideas has a three-month window of opportunity to develop a new product using new pattern recognition software the company recently created. Surprisingly, the software adapts easily to different applications. Really Big Ideas only has the resources and time to develop one of two projects, or to develop none. Project Managers Aisha Ali and Ben Bertrand arrive. After brief introductions, Aisha Ali launches her pitch. She says that a smoke and fire detector is the best project to make. The detector goes beyond ordinary smoke detectors. It can detect flames as well as smoke. It will cost $100,000 to develop, and if it succeeds the Business Analysis department says it will generate revenue of $1,000,000. Not to be outdone, Ben Bertrand announces that a motion detector device is the best project to develop. The motion detector, which uses conventional household lighting, will only cost $10,000 to develop. He adds that the analysts expect such a device to generate $300,000 in revenue.

Smith asks if you have any questions, so you carefully ask about the chances for success. Both project managers agree that Samiksha Singh, the Director of the Business Analysis department, has that information. Smith initiates a conference call with Samiksha Singh. Singh informs the meeting that the smoke and fire detector has a 50% chance of success, and that the motion detector has an 80% chance of success.

Smith thanks all the participants and ends the meeting. It is now 10:30 a.m. Smith announces that he'll return within the hour to see if you have decision analysis.

Smith leaves you with your notes, paper, pen, and a calculator. Can you help Really Big Ideas to decide which product, if either, to develop? How can you evaluate the alternatives in a measurable way given the various uncertainties involved? You can use a decision tree to describe and then to evaluate the decision alternatives.

2.1 Describe decision alternatives and outcomes

You can now start your decision tree. A decision tree is a diagram of nodes and connecting branches. Nodes indicate decision points, chance events, or branch terminals. Branches correspond to each decision alternative or event outcome emerging from a node.

2.1.1 The first decision (root node)

Start by drawing a small square on the left side on a piece of paper. This is called the root node, or root. The root node represents the first set of decision alternatives.

For each decision alternative draw a line, or branch, extending to the right from the root node. Allow a generous amount of space between the lines to add information. Some branches may split into additional decision alternatives or outcomes. You can also "bend" branches so that the lines line up horizontally. These techniques make keeping track of alternatives easier. (See figure 2.1.1)

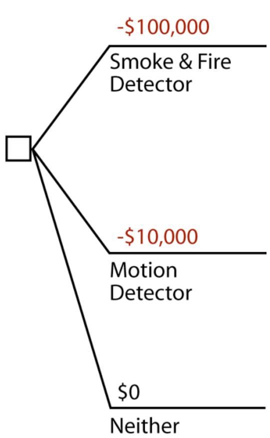
Label each branch with the decision and its associated investment cost. Write that the smoke and fire detector will cost (-$100,000) to develop. Similarly, write that the motion detector will cost (-$10,000) to develop. Write $0 at the third branch corresponding to the alternative to develop neither product.

Tip

Show the costs as negative values since they represent a "preliminary loss." Any future gross revenue will be offset by costs. Showing costs as negative values simplifies the calculation of payoff.

Figure 2.1.1

The root node is the small square at the left. Branch lines emerge from the root towards the right. Each branch represents one decision alternative.

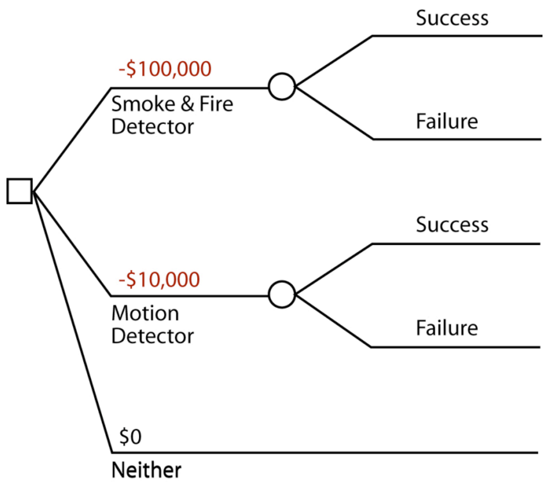


2.1.2 Chance outcomes

In the Really Big Ideas scenario each product development effort can have one of two outcomes: each project can either succeed or fail. Draw a small circle, or chance node, at the end of the branch for the smoke and fire detector. Draw a chance node at the end of the branch for the motion detector. From each chance node draw two branches towards the right; one branch represents success and the other represents failure. Label the branches accordingly.

Figure 2.1.2

Chance nodes, shown as small circles, lead to two or more possible outcomes. Draw each outcome as a branch from the chance node.



2.1.3 Endpoints and payoffs

You can now complete all the branches with endpoints, since there is no further branch information to represent. Draw a small triangle (◁) at the end of each branch to represent the endpoint. Write the payoff value at the endpoint. In business applications the payoff is usually a monetary value equal to the anticipated net profit, or return on investment. Net profit (or net loss) is the difference between the investment cost and the total revenue. A positive value indicates a net profit, while a negative value indicates a net loss. In other words, if revenue exceeds investment, then the effort is profitable. Otherwise the effort is a net loss, or a break-even result if the payoff is zero.

For Really Big Ideas, a successful smoke and fire detector project will earn $1,000,000 in gross revenue. The resulting net profit therefore equals the sum of the gross revenue and the investment cost. Recall that cost can be represented as a negative number. The calculation is therefore $1,000,000 + (-$100,000) = $900,000 net profit, or payoff. Write $900,000 at the end of the branch for success of the smoke and fire detector.

However, if the smoke and fire detector project is not successful, then no revenue will be earned and all the investment will be lost. The calculation for this event is $0 + (-$100,000) = (-$100,000), a loss or negative payoff. Write (-$100,000) at the end of the branch for failure of the smoke and fire detector.

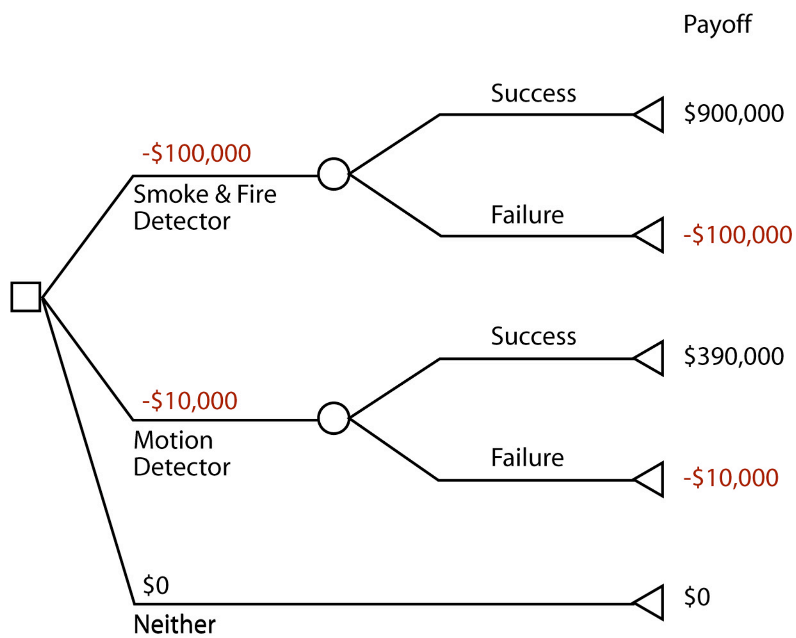
Perform a similar calculation for the success and failure payoffs for the motion detector. Your results should show a $290,000 payoff if successful, and a (-$10,000) payoff (a loss) if it fails. Write these values at the endpoints of their respective branches.

The payoff for the decision branch to not develop either project is simply $0.

See figure 2.1.3.

Figure 2.1.3

Use endpoints, shown by small triangles with one point connecting to the branch, to indicate that there are no further outcomes or decisions to consider. Write payoff values for each terminated branch to the right of the endpoints.



This concludes the basic structure of the decision tree for the Really Big Ideas alternatives. We can now incorporate the likelihood of success and failure and use that to analyze the decision alternatives.

2.2 Incorporate uncertainty (outcome probability)

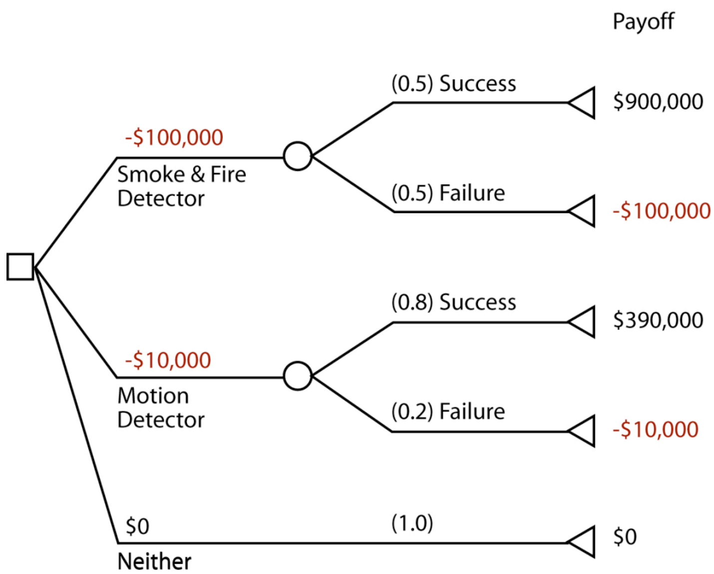
You can now incorporate the relative outcome probability, or uncertainty, associated with each chance event. You can express probabilities as percentages or as decimal fractions. This primer adopts the common decision tree convention of using decimal fractions from (0.0) to (1.0), in which (1.0) = 100%.

In the Really Big Ideas scenario, the smoke and fire detector has a 50% chance of success, and therefore a 50% chance of failure. Therefore, write (0.5) on the success branch and (0.5) on the failure branch. The motion detector has an 80%, or (0.8) chance of success, and therefore a 20%, or (0.2) chance of failure. Write these values on their respective branch lines.

See figure 2.2.

Figure 2.2

Write the probability for each outcome branch. You can express a probability as a decimal fraction in parentheses.



2.3 Find the expected value (EV)

You are now ready to evaluate the relative merits of each decision alternative. Expected value (EV) is the way to combine payoffs and probabilities for each node. The higher the EV, the better a particular decision alternative on average when compared to the other alternatives in the decision tree.

You calculate the EV for any chance node by summing together all the EVs for each branch that is connected to the node. The general formula for calculating EV at any chance nodes is given as:

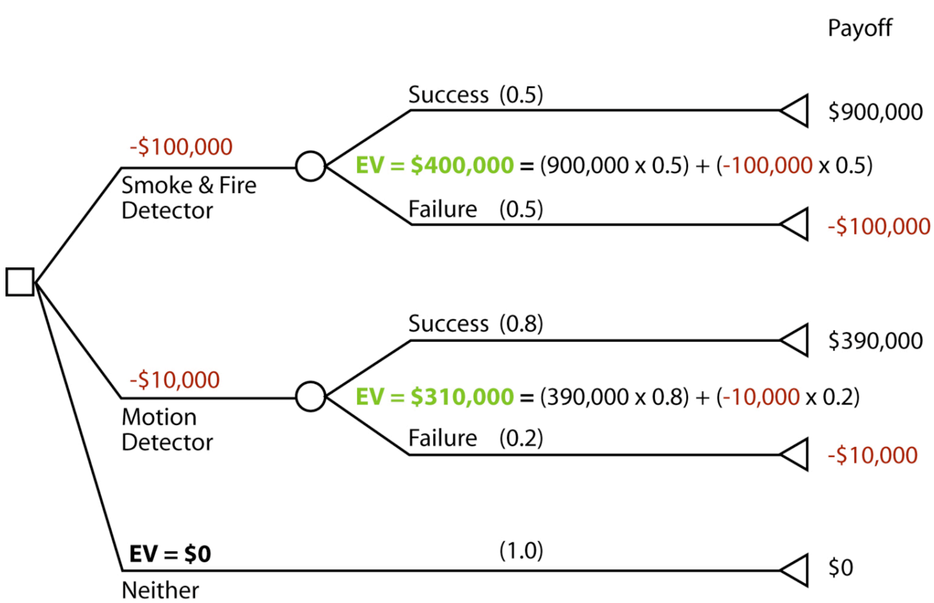
$EV_{chance\ node} = EV_{branch1} + EV_{branch2} + \ldots + EV_{branchN}$

- In the Really Big Ideas scenario, if the smoke and fire detector is successful, the EV is the payoff (profit) multiplied by its probability, or \$900,000 x 0.5 = \$450,000.
- The EV if the fire detector project fails is (-\$100,000) x 0.5 = (-\$50,000).
- The EV for the decision to develop the smoke and fire detector (incorporating both success and failure) is the sum of the EV for all the eventualities.
  $EV_{node} = (EV_{success} + EV_{failure})$ = \$450,000 + (-\$50,000) = \$400,000.
- Similarly, the EV for the decision to develop the motion detector is given by
  EV = (\$390,000 x 0.8) + [(-\$10,000) x 0.2] = \$310,000.

Write the EV for each node near that node. See figure 2.3.

Figure 2.3.

Expected value (EV) is the sum of all the combined payoffs and probabilities for each chance node.



The smoke and fire detector project has a higher EV than the motion detector. You can report the analysis with these summarized presentation points:

- The smoke and fire detector is the better project to develop, despite the greater risk. The significantly larger anticipated profits make the risk more acceptable than the competing project.
- The motion detector is less risky, but also significantly less profitable. With the given profit expectations the project does not overcome the expected value of its rival project.

Exercise

Try different possible payoff and/or probability combinations to raise the EV for the motion detector. What combinations would make this EV superior to the smoke and fire detector?

Note

Do not confuse EV with any particular payoff amount that would be earned for any specific instance of the gambit. EV is only the average payoff if the trial were repeated many times. Many real-world decisions do not have the advantage of being repeatable. Nevertheless, probabilities can still be assigned to outcomes based on information from expert judgment and other means of risk analysis. Such methods are beyond the scope of this primer. For the purposes of this primer assume that the examples use realistic probabilities from reliable sources.

2.4 Add a sequential decision

Consider the following information, which continues the Really Big Ideas decision scenario.

Vice President Adam Smith of Really Big Ideas, Inc. calls you the following day. He reports that the company has learned new information that may affect the decision. Smith wants to know if you can prepare a new analysis using the new information. Smith tells you that the proposed smoke and fire detector must pass an Underwriters Laboratories (UL) safety certification before it can be sold. (Such certification is not necessary for the motion detector). Director Samiksha Singh has interviewed a UL inspector and learned how the certification process works. Singh has modified the marketing and success estimates based on the new information. She now reports the following:

- A commercial grade certification will result in $1,000,000 sales (as originally expected). However, the likelihood of obtaining the coveted commercial certification is only 30% due to the stringent standard.
- A less-stringent residential grade certification is 60% likely, but would result in only $800,000 sales.
- There is a 10% chance that the smoke and fire detector will not pass any certification test. In this case—a complete failure—the company will lose the initial $100,000 investment cost.
- Underwriters Laboratories charges a $5,000 non-refundable fee for the certification application.

Your job is to construct and then evaluate a new decision tree based on this new information.

2.4.1 Construct a decision tree

Begin the revised decision tree at the left and through the first chance event nodes as in the prior version. The results for the motion detector and no project remain unchanged.

The chance node for the successful development of the smoke and fire detector can now lead to a new decision node; represent this new decision node with a small square. The decision at this node is whether to submit an application for the UL safety certification. There are only two choices possible: submit an application, at an investment of $5,000, or do not submit an application. You may guess that failure to submit the application after successful project development does not make good sense, and this is correct. The decision tree shows that your guess is correct. You "resolve" decision nodes in terms of the branch with the highest EV. Therefore a "failure to submit application" branch does not play a role in the value of its decision node.

The "submit application" path leads to one of three possible outcomes: commercial grade, residential grade, or no certification. The probability of each outcome is 0.3, 0.6, and 0.1 respectively. Write these probabilities on their respective branches.

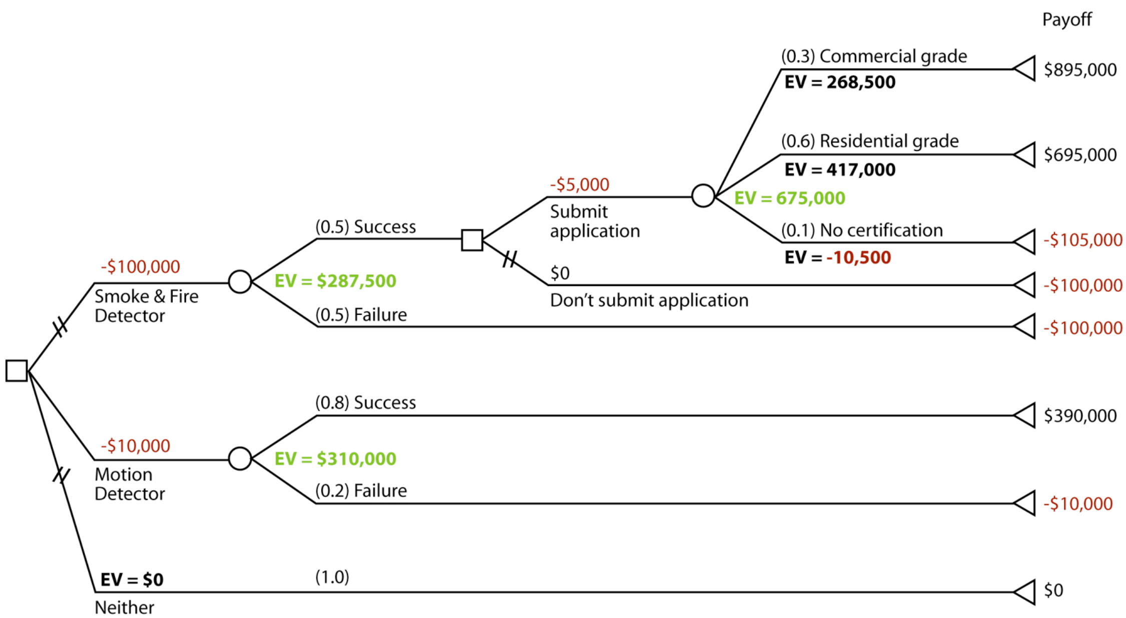
The commercial grade outcome terminates with a payoff calculated as follows:
revenue + development cost + application cost =
$1,000,000 + (-$100,000) + (-$5,000) = $895,000.

In a similar way, the residential grade outcome terminates with this payoff:
$800,000 + (-$100,000) + (-$5,000) = $695,000.

If the device does not earn a certification it cannot be sold with a UL certification. This situation dooms its marketing prospects to no revenue and a loss of the investments. In that case:
$0 + (-$100,000) + (-$5,000) = (-$105,000), a loss.

Write each payoff near the matching endpont as you calculate its value. See figure 2.4.1.

Figure 2.4.1



This is an example of a sequential decision. The original root decision leads to at least one other decision on some branch path. The second decision leads to further chance events. Add decision nodes representing how they must occur in time on a branch path. A decision tree can help you keep track of many such sequential decisions.

2.4.2 Recalculate the expected values

You are now ready to find the EV for the chance event node representing the UL safety certification.

Recall that for any chance node,
$EV_{\text{chance node}} = [EV_{\text{branch1}} + EV_{\text{branch2}} + . . . +EV_{\text{branchN}}]$.

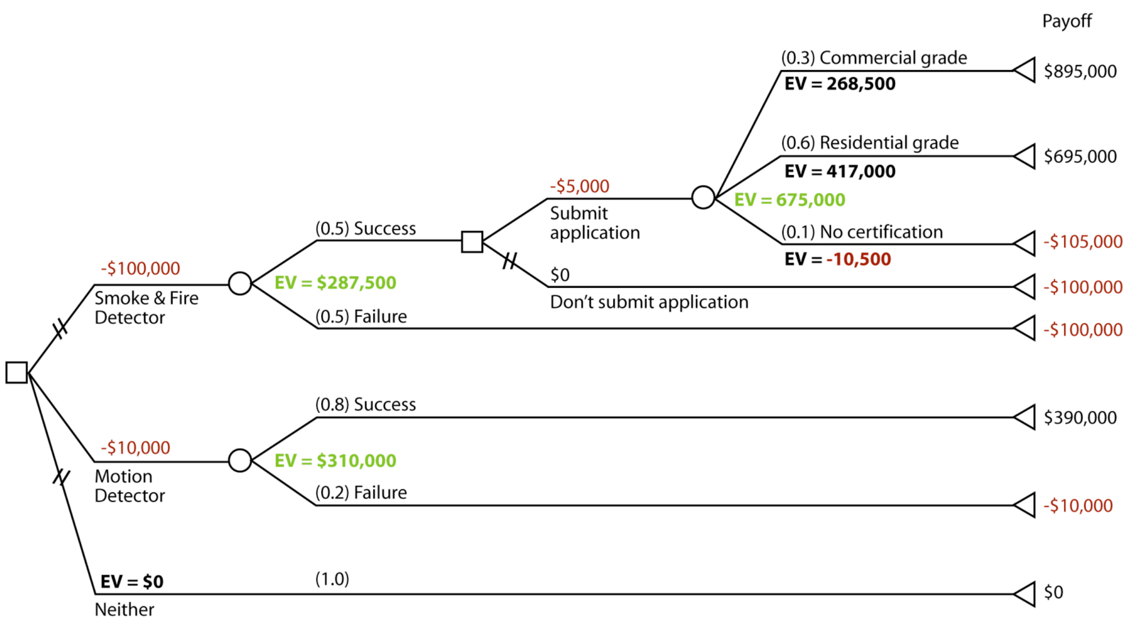
Therefore,
(\$895,000 x 0.3) + (\$695,000 x 0.6) + [(-\$105,000) x 0.1] = \$675,000.

This chance node is thus resolved or collapsed into a single EV, in this case \$675,000. Now use this amount as the payoff value for the "submit application" branch of its decision node.

You may notice that the "don't submit application" branch also can have an expected value, in this case (-\$100,000). You resolve a decision node in terms of the greatest decision branch EV and disregard any lower values. Use double-hatch marks to indicate a branch from a decision node that is disregarded.

You can now calculate the chance event node for the smoke and fire detector development outcome. The input from the "success" branch is \$675,000 x 0.5. And the input from the "failure" branch remains at: (-\$100,000) x 0.5. Therefore, the
EV = (\$675,000 x 0.5) + (-\$100,000 x 0.5) = \$287,500. See figure 2.4.2.

Figure 2.4.2



The calculation in figure 2.4.2 is an example of successively calculating the expected values from endpoints back through branches and nodes. Such a rollback calculation takes the EV from a given node and uses that value as a payoff input for the prior node.

2.4.3 Analyze the changes

The motion detector has now become the better choice. The new information dramatically reduces the EV for the smoke and fire detector. What is the main reason for the lower EV?

One million dollars revenue is still possible with a commercial grade safety certification, but the likelihood of that outcome is only 30%. Substantial revenue of $800,000 with a 60% outcome is still possible with a residential grade certification. However, that is not enough to offset the resulting lower EV at this node. Since you must use this EV as the input for the development outcome chance node (with only a 50% chance of success) the overall EV for the smoke and fire detector falls below that of the motion detector.

The certification process itself is not the culprit in reducing the EV for the smoke and fire detector. The $5000 investment cost barely affects the EV calculations. The small chance of no certification is also only a small factor.

Instead, the main reason is the relatively modest probability of obtaining the optimal commercial certification. This lowered probability multiplied by the anticipated revenue significantly lowers the overall EV for that branch. Even if the probability of obtaining a commercial-grade certification is increased to 50% the resulting EV is still less than that for the motion detector.

This analysis suggests two main factors that readily affect the EV for the smoke and fire detector. One factor is anticipated revenue. The other is the chance of obtaining the optimal commercial-grade certification. How much would either factor need to improve in order to make the smoke and fire detector the better decision?

You can confidently summarize your report to Really Big Ideas with these presentation points:

- The smoke and fire detector is now significantly more risky since greater uncertainty exists in knowing which certification grade may be obtained.
- The smoke and fire detector profits are also potentially lessened, especially if a commercial grade certification is not obtained.
- Together, this combination of greater risk and potentially fewer profits from a less desirable market significantly reduces the attractiveness of the smoke and fire detector project.

Exercise

Try different possible payoff and/or probability combinations to raise the EV for the smoke and fire detector. What combinations make this EV superior to the motion detector?

3.0 Basic Concepts

You can use the decision tree method by mastering a few basic concepts. Use this section to become familiar with these ideas and notation. If you are using this primer for the first time you will probably find the easiest path is to review the material in the following order.

3.1 Decision tree notation (nodes and branches)

3.2 Payoff values

3.3 Outcome probability

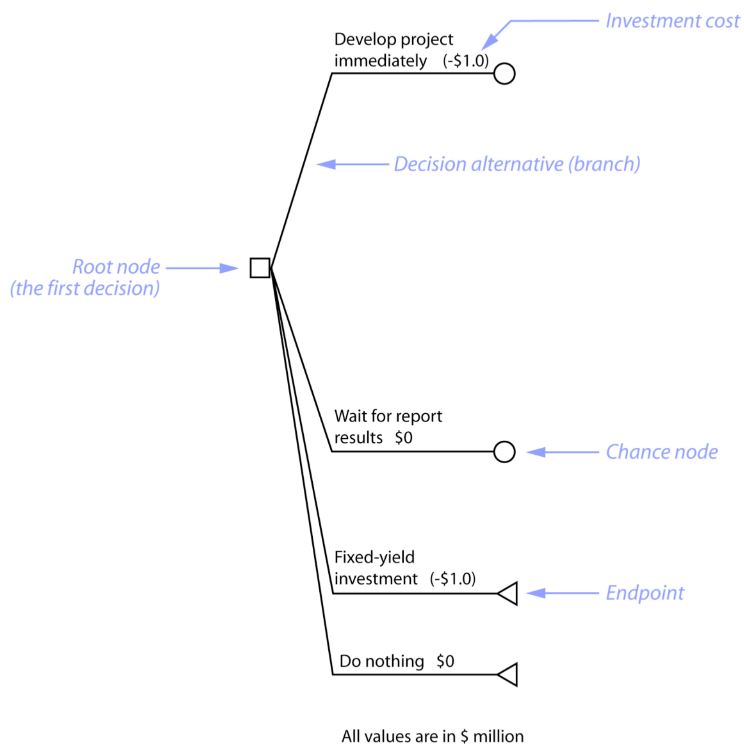
3.4 Expected value

3.5 Decision tree analysis

3.1 Decision tree notation (nodes and branches)

Any decision includes two or more decision alternatives. Any decision alternative might lead to multiple possible outcomes. One outcome may depend on another, a situation called dependent uncertainty. Decisions may also be linked in a sequence, a condition called sequential decisions. Use decision tree notation to keep these myriad paths and possibilities easy to understand and compare.

Figure 3.1



Example

In figure 3.1 a company is evaluating whether to invest $1M in a project immediately or wait for a marketing report that may affect project development.

Two other alternatives are also possible: invest $1M in a fixed yield bond or do nothing. A fixed-yield investment and doing nothing are examples of baseline alternatives: choices that can be used to compare the overall merits of the decision alternatives.

3.1.1 Decision nodes and the root node

Small squares identify decision nodes. A decision tree typically begins with a given "first decision." This first decision is called the root node. For example, the root node in a medical situation might represent a choice to perform an operation immediately, try a chemical treatment, or wait for another opinion.

Draw the root node at the left side of the decision tree.

3.1.2 Chance nodes

Small circles identify chance nodes; they represent an event that can result in two or more outcomes. In this illustration two of the decision alternatives connect to chance nodes. Chance nodes may lead to two or more decision or chance nodes.

3.1.3 Endpoints

An endpoint, or termination node, indicates a final outcome for that branch. Small triangles identify endpoints. Show an endpoint by touching one point of the triangle to the branch it terminates.

3.1.4 Branches

Lines that connect nodes are called branches. Branches that emanate from a decision node (and towards the right) are called decision branches. Similarly, branches that emanate from a chance node (and towards the right) are called chance branches. In other words, the node that precedes a branch identifies the branch type. A branch can lead to any of the three node types: decision node, chance node, or endpoint.

Tip

Draw branches from the root node with a generous amount of space between the branches. As branches extend outwards they may spawn any number of additional nodes and branches.

Start with enough room between branches to easily accommodate the alternatives and outcomes that may result.

3.2 Payoff values

The payoff value is equivalent to the net profit (or net loss) expected at the end of any outcome. Write payoff values at their respective branch endpoints. Although you can express payoff in various ways, it is common to use monetary units in most business applications.

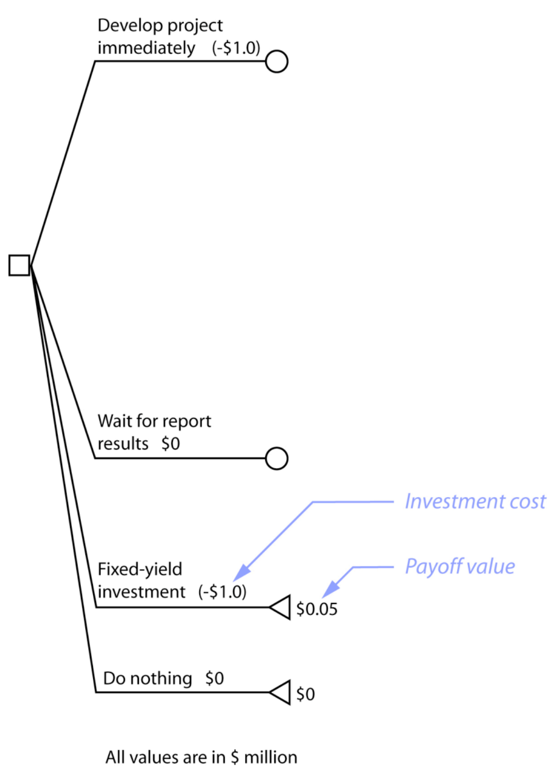
Payoff is the difference between investment cost and gross revenue. This primer adopts the convention of indicating investment costs as negative values to simplify calculating payoff values.

Payoff values can be positive or negative. Negative payoff values indicate a net loss.

Tip

Write the investment cost associated with a decision alternative on the branch. This helps keep the cost in mind when calculating the payoff values. Also write the investment cost as a negative value to show that it must reduce any projected gross revenue.

Figure 3.2



Example

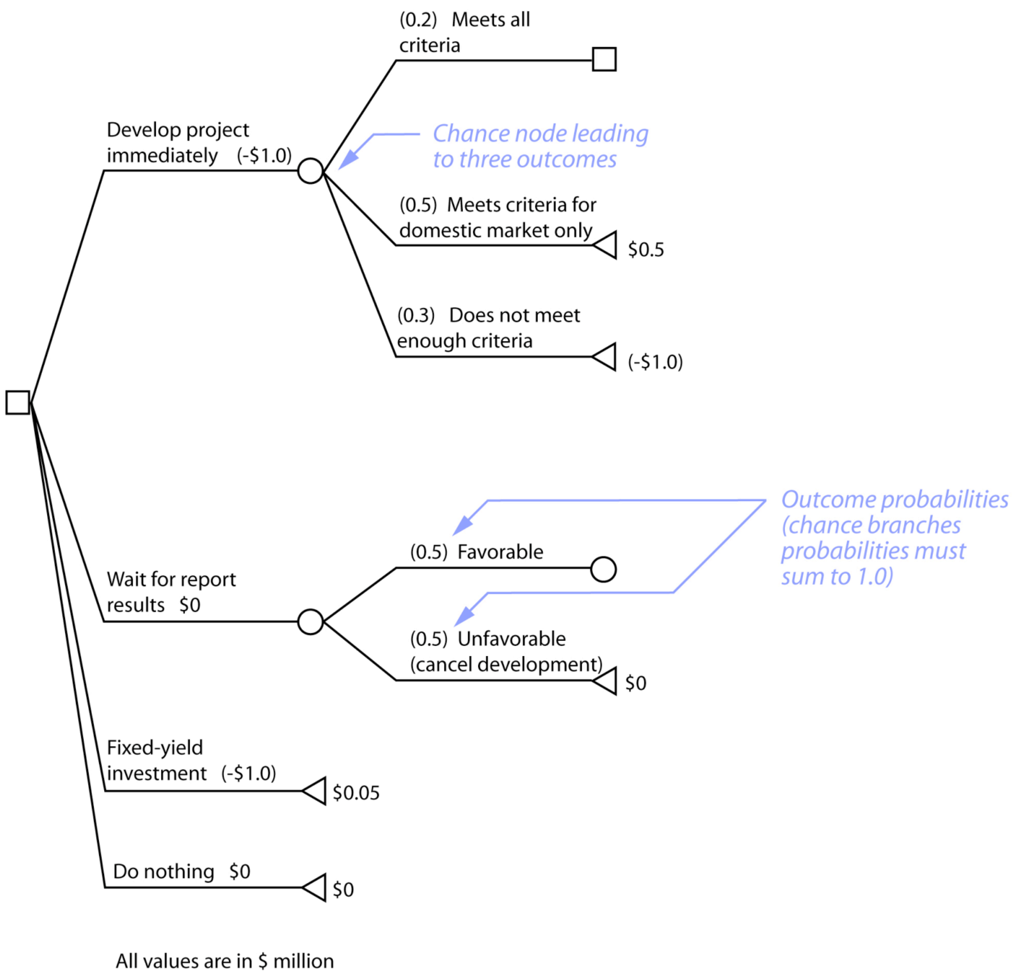
Figure 3.2 shows the expected payoffs at two endpoints. The fixed-yield investment results in $1,050,000 revenue, and therefore a $50,000 payoff. The payoff for doing nothing is $0. The other branches lead to chance nodes at this stage of the decision tree. You can assign payoff values only after these chance nodes lead to endpoints.

3.3 Outcome probability

A chance node leads to two or more outcomes, each outcome represented by a new branch. As with a game of chance, an outcome has a particular probability of happening. The total of all outcomes for a given chance node must equal 100% (or 1.0).

A standard decision tree convention expresses probabilities as decimal fractions in parentheses at the chance branches.

Figure 3.3



Example

In Figure 3.3, the decision alternative to develop a project immediately can lead to one of three outcomes. The company has determined that there is a 20% chance that the project can meet all the criteria for success in international and domestic markets, but a 50% chance that the project will only meet the criteria for the domestic market. In addition, is a 30% chance that the project will not meet enough criteria for either market as a result of insufficient information.

The company can also wait for a marketing study before developing the project. The marketing information may help the company create a successful project. But the information may also suggest unfavorable conditions that the company probably cannot overcome. The company uses its best judgment and guess, with a 50% favorable and a 50% unfavorable outcome.

The decision tree shows these probabilities as decimal fractions in parentheses on their respective chance branches.

3.4 Expected value

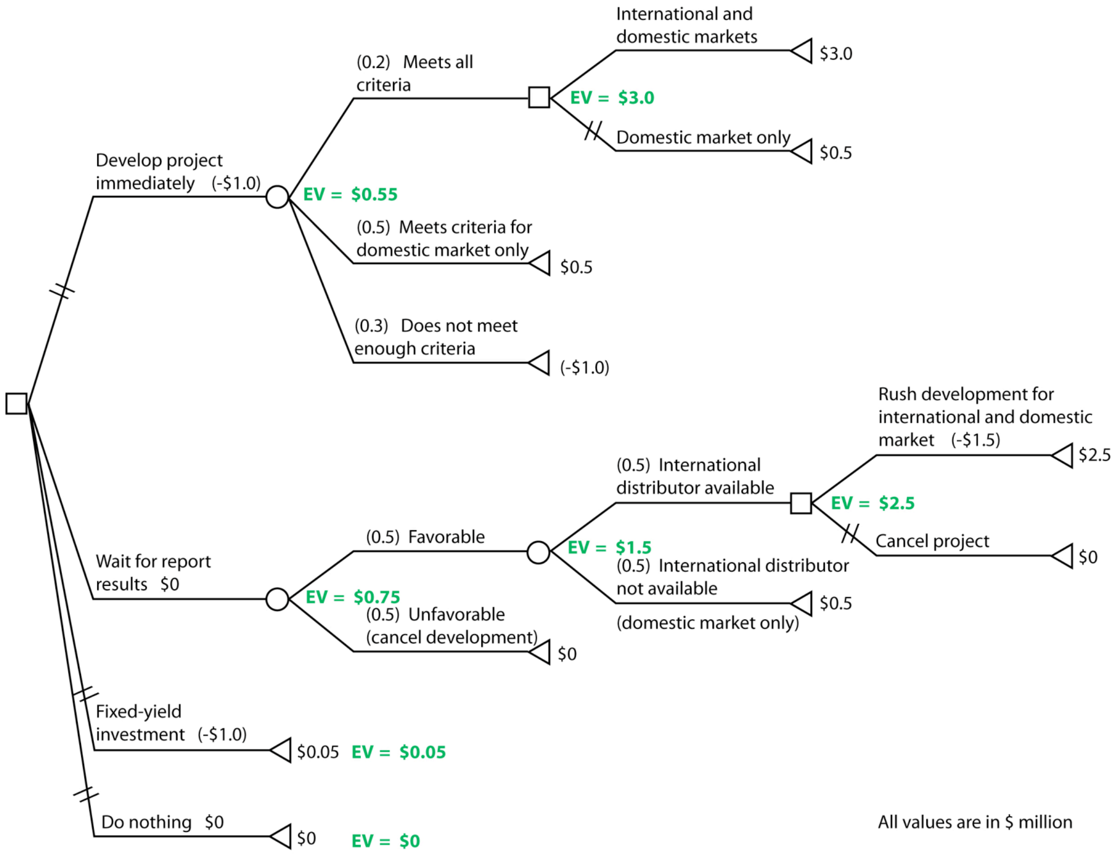
Expected value (EV) is a way to measure the relative merits of decision alternatives. The expected value term is a mathematical combination of payoffs and probabilities. You calculate the expected values after all probabilities and payoff values are identified.

The goal of the calculations is to find the EV for each decision alternative emerging from the root node. For the purposes of this primer, the decision alternative with the highest EV is the best choice. See figure 3.4.

Although you can apply the formal definition of expected value, in practice you can calculate EV calculations by applying the following rules. To calculate EV, start from the endpoints and work back towards the root. An easy way to find expected values is to calculate an EV for each terminated branch, then each chance node and each decision node.

- For a terminated decision branch, EV is equal to the payoff.
- For a terminated chance branch, EV is the product of its payoff and probability.
- For a chance node, EV is the sum of each chance branch payoff multiplied by the probability for that payoff.
- For a decision node, EV is the greater EV value of any decision branch. Mark the lower value EV branches with double-hatch marks to disregard these branch paths. Since the root node is also the first decision node, the decision alternative with the greater EV is the overall best decision.
- As the calculations are carried from right to left, use a “resolved” EV at any node type as the payoff “input” at the node closer to the root.

Figure 3.4



Tip

Start an EV calculation from the endpoint and then proceed from right to left. The EV for a node becomes the payoff "input" for the subsequent EV calculation to the left. For example, in figure 3.4, use the EV for the topmost decision node (types of markets to enter) as an input to calculate the chance node (criteria outcomes).

Example

In figure 3.4, calculate the EV for the decision alternative to develop the project by following the given EV rules:

- Decision node ("international and domestic marketing" vs. "domestic marketing only"). The EV is the greatest value given by all the decision branches, $3,000,000. This value then becomes the payoff "input" for the next node to the left.
- Chance node ("all criteria" vs. "domestic criteria only" vs. "not enough criteria"). [$3,000,000 x 0.2] + [$500,000 x 0.5] + [(-$1,000,000) x 0.3] = **EV = $550,000**.

This value becomes the payoff "input" for this alternative when considering the root node.

- By a similar calculation, the EV for the alternative to wait for the report before deciding whether or not to develop the project is **EV = $750,000**. This value becomes the payoff "input" for this alternative when considering the root node.
- The EV for the alternative to invest the capital in a fixed-yield investment is just the payoff value, **EV = $50,000**.
- The EV for doing nothing is **EV = $0**.

3.5 Decision tree analysis

The EV at the root node shows that the decision to wait for the marketing report is the best decision. This result may come as a surprise. You can better understand the result after calculating expected values.

Example

Before the decision tree in Figure 3.4 is analyzed you may be tempted to assume that the decision to develop the project immediately is the better choice. After all, the project will only cost $1,000,000 instead of a rushed cost of $1,500,000. Furthermore, there are fewer complications to consider, like waiting to determine the potential for international distribution.

The EV for the decision alternative to wait for the report is complicated by two major chance factors. One factor is that the company knows that waiting makes finding an international distributor more difficult than if the project begins immediately. The company has determined that the likelihood of finding an international distributor is less certain (by 50%) if they wait for the report.

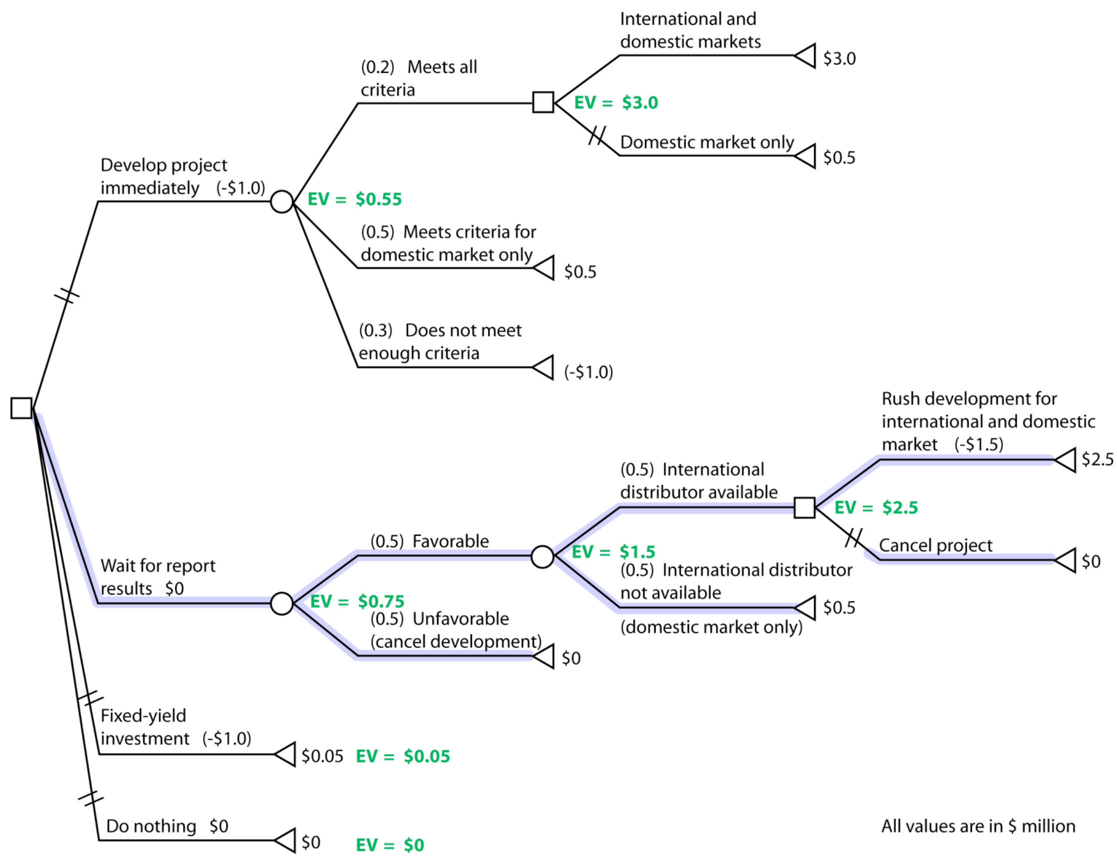
The other chance factor is the information in the marketing report. The company estimates that the marketing report has a 50% chance of delivering favorable data which will help project development. Two or more chance nodes directly connected in this way indicate a dependent uncertainty, a condition that can readily be evaluated through decision tree analysis.

Another complication is that rushing development raises development costs by a third, to (-$1,500,000), and this alone reduces the payoff for the international and domestic marketing by $500,000.

The decision tree method requires probabilities for all chance outcomes. In this example, the successive chance outcomes of waiting for report results and then securing an international distributor reduce the EV along the branch path.

But a similar analysis of the competing decision alternative reveals important information. Without the benefit of the marketing report the chances of "getting it right" for the international market are fairly low, at 20%. This factor significantly weakens the value of that branch. This alternative is also risky; there is a 30% chance that the company will lose all investment costs. The absence of reliable market information means that the project may not meet criteria for success in any market.

Figure 3.5



The analyst can sum up the decision tree analysis with the following major presentation points and with the decision tree in figure 3.5.

- The international market potential is $3,000,000 in revenue, while the domestic market is only $500,000.
- Immediate project development costs only $1,000,000.
- Waiting to develop the project results in rush costs, pushing the total to $1,500,000.
- Marketing information plays the most important role in the potential success of this project. In the absence of valid marketing data, the chance for success in the international market is poor (20%) and the chance for complete failure is sifnificant (30%). These risk factors significantly reduce the potential for product success.

- Waiting for the marketing report can complicate project development. There is a 50% chance that the report will be favorable enough to proceed. Waiting also reduces the chance (by 50%) for recruiting a distributor in time to capture the international market. However, these risk factors of waiting do not affect the chance of success as much as the absence of marketing data.
- Therefore the best decision, given the known assumptions, uncertainties, and information, is to wait for the results of the marketing report before deciding to develop the project.

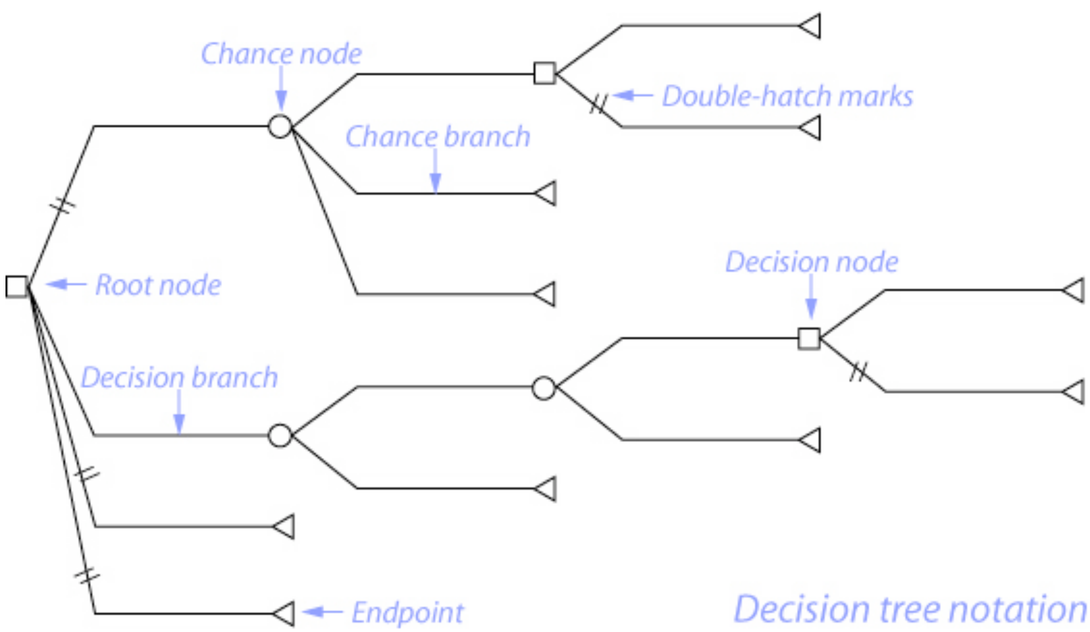
Exercise

If you haven't done so already, review the **Decision Scenario** exercise.

4.0 Glossary

The terms given in this glossary can be applied for business applications and this primer. Other applications such as medicine, artificial intelligence, or general problem solving may use non-monetary value calculations.

Figure 4.0



Branch: A particular decision alternative or chance outcome is called a branch. A branch representing a decision alternative emanates from a decision node. A chance branch (chance outcome) emanates from a chance node.

Branch path: A branch path is a series of connected branches leading from a decision node through any given endpoint.

Chance branch (chance outcome): A chance branch is one of the possible outcomes emanating from a chance branch. In a decision tree two or more chance branches are lines drawn to the right from a chance node.

Chance node, or chance event node: A chance node identifies an event in a decision tree where a degree of uncertainty exists. A chance node represents at least two possible outcomes. Chance nodes are shown by small circles in a decision tree.

Cost: A cost is any monetary expense required for a particular decision alternative or that must be paid at a particular chance outcome. Typical cost examples are investments (on decision branches) and penalties (on chance branches). In this primer, investment costs are shown as negative values.

Data mining: Data mining is a process that uses software to explore information stored in databases for trends and patterns.

Decision alternative: Any decision involves a choice between two or more decision alternatives. In a decision tree, a branch emanating from a decision node represents each decision alternative.

Decision branch: A decision branch represents a particular decision alternative. In a decision tree, two or more decision branches are lines drawn to the right from a decision node.

Decision node: A decision node represents a location on a decision tree where a decision between at least two possible alternatives can be made. Decision nodes are indicated by small squares in a decision tree.

Decision strategy: A decision strategy is a particular branch path in a decision tree and includes all the decisions and chance events along that branch path. A decision tree generally includes two or more possible decision strategies. One decision strategy is generally found to be the "preferred decision strategy" since decision strategies can be compared by computing their respective expected values (EV).

Decision tree: A decision tree is a diagram used to describe decision alternatives and chance events.

Decision tree analysis: Decision tree analysis is the process of evaluating alternative decision alternatives emanating from the root node. The analysis requires calculating and then comparing expected values. The analysis can also involve making adjustments to probabilities and payoff values to determine how changes to those values may affect expected values.

Decision tree notation: A set of graphic symbols and conventions used to describe elements in a decision tree. Commonly used decision tree notation includes decision nodes, chance nodes, endpoints, branches, and double-hatch marks.

Dependent uncertainty: A dependent uncertainty is a condition whereby a chance event depends on a prior chance event. For example, if the chance of event "B" will occur depends on the chance that event "A" will occur, then some of the uncertainty associated with "B" depends on "A." In a decision tree, a chance node that is directly connected to another chance node indicates a dependent uncertainty.

Double-hatch marks: Double-hatch marks are a pair of small lines that are placed over a branch to indicate that particular branch is not to be considered in an expected value calculation.

Endpoint: An endpoint is a node that terminates a branch (and also a branch path). In a decision tree, an endpoint is drawn as a small triangle, with one apex connected to the branch. The endpoint is the location where a payoff value is identified. A decision tree is "terminated" when all the branch paths result in an endpoint with a payoff value.

Expected value: Expected value is a criterion for making a decision. Expected value is a mathematical term that combines the payoffs and probabilities of possible chance outcomes for a decision alternative.
Technical note: The expected value represents the "average payoff value" expected if a

decision were to be repeated many times. The term depends on the relative likelihood of events occurring if the decision were repeated many times while the circumstances remain constant. Many real-world decisions do not have the advantage of being repeatable. Nevertheless, probabilities can still be assigned to outcomes based on information from expert judgment and other means of risk analysis. Such methods are beyond the scope of this primer. For the purposes of this primer assume that the examples use realistic probabilities from reliable sources.

EV: EV is an abbreviation for expected value.

Investment cost: An investment cost is the monetary amount to be allocated at a decision branch. In this primer, investment costs are shown as negative values.

Node: A node is a symbol in a decision tree indicating decision alternatives, chance outcomes, or a branch termination.

Payoff or payoff value: A payoff is a monetary amount that will be earned at the conclusion of a branch path. Payoff, also called net profit in business applications, is the difference between the costs and the gross revenue earned. A positive payoff is equivalent to a positive net profit. A negative payoff is equivalent to a net loss.

Rollback or rollback calculation: Rollback is the process of successively calculating expected value by beginning at an endpoint and calculating subsequent expected values back towards the root node.

Return on investment: Return on investment (ROI) is another term for payoff (or net profit or loss).

Root node: The root node is the initial decision node from which a decision tree is established.

Sequential decision: A sequential decision is a situation in which more than one decision may be required before a decision tree can be terminated. All but the simplest decision trees contain sequential decisions.

Spreadsheet: A spreadsheet is a software application used for managing multiple calculations. Microsoft Excel® is the leading spreadsheet application on Windows and Mac OS operating systems.

Termination node: A termination node is an endpoint.

5.0 More to Explore

Decision tree software spans low-cost spreadsheet plug-ins to server-mediated applications suites. Students and casual users may find the free trial offerings from Decision Support Services, Visionary Tools, or Lumenaut particularly useful.

- **Lumenaut**
  Lumenaut is a Microsoft Excel plug-in. The company offers a free trial and a free student version.
  http://www.lumenaut.com/
- **Salford Systems**
  TreeNet for Windows is among other decision analysis products used for data mining in complex database systems.
  http://www.salford-systems.com/
- **Treeplan.com** (Decision Support Services)
  TreePlan is a low cost Microsoft Excel plug-in that works on Windows or Macintosh. A free trial version is available for 15 days. The plug-in is $29, or can be purchased as part of a low cost suite of products.
  http://www.treeplan.com/
- **Vanguard Software Corporation**
  Vanguard Studio is a customizable software tool aimed at business development. Single user licenses begin at $1,000. The company web site also offers a short introduction to decision trees.
  http://www.vanguardsw.com/
- **Visionary Tools**
  Occam's Tree is a stand-alone application (Windows-only). This small German company offers a free trial version and a single license for $88.
  http://www.visionarytools.com/

You can find other information on decision trees and related decision analysis at a number of online sources. The following represent some of the best for students.

- ***Decision Tree Primer***, by Craig W. Kirkwood, Department of Supply Chain Management, Arizona State University. © 2002.
  Kirkwood is an author and instructor focusing on general decision analysis. This short text is a particularly useful introduction to decision analysis, risk aversion, and valuing information. The author of the present online primer gratefully acknowledges the Kirkwood text from pages 5-18 for useful definitions and examples.
  http://www.public.asu.edu/~kirkwood/DAStuff/decisiontrees/index.html
- **Interactive Textbook on Clinical Symptom Research, Chapter 14: Tools for Decision Making, Part II: Expected Value Decision Making**, by Harold Sox, MD
  This online resource offers insights into how decision tree analysis can be used in

medicine.
http://symptomresearch.nih.gov/chapter_14/Part_2/sec1/chspt2s1pg1.htm

- **Wikipedia**
  This popular online encyclopedia contains several relevant entries.
  Decision trees: http://en.wikipedia.org/wiki/Decision_tree
  Expected value: http://en.wikipedia.org/wiki/Expected_value
- **Mindtools, Decision Tree Analysis**
  This web resource offers a broad range of information aimed at business professionals. This particular entry offers an introduction and links to related information.
  http://www.mindtools.com/dectree.html