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Decision Analysis

Why do managers often find making decisions difficult? First, uncertainty is inherent in most important decisions. A product manager, for example, must decide whether to market a new product, even though she is uncertain of production costs, consumer receptivity, and how the competition might react. A second reason is that decision makers must balance many conflicting objectives. A division manager may decide to invest in a new product that has the potential to be a blockbuster in ten years, even if the division's morale and short term profitability suffer. Third, the large number of alternatives a manager must evaluate often serves to confuse and even paralyze the decision maker. Finally, a manager often does not even know the full set of alternatives from which to choose.

In short, it often becomes too difficult to make a decision based only on intuition; formal analysis may be necessary. *Decision analysis* is a logical and systematic approach for analyzing decision problems. It takes a "divide and conquer" approach to decision making, breaking down the process into a number of steps (summarized in **Figure 1**):

1. *Decision structuring:* Identify

   a. the set of ***alternatives*** from which to choose;

   b. the set of critical ***uncertainties*** that affect the outcomes of the decisions;

   c. ***criteria*** for choosing among the competing alternatives.

2. *Assessment and information gathering:* Collect relevant information

   a. assessing the likelihood of the various uncertain events;

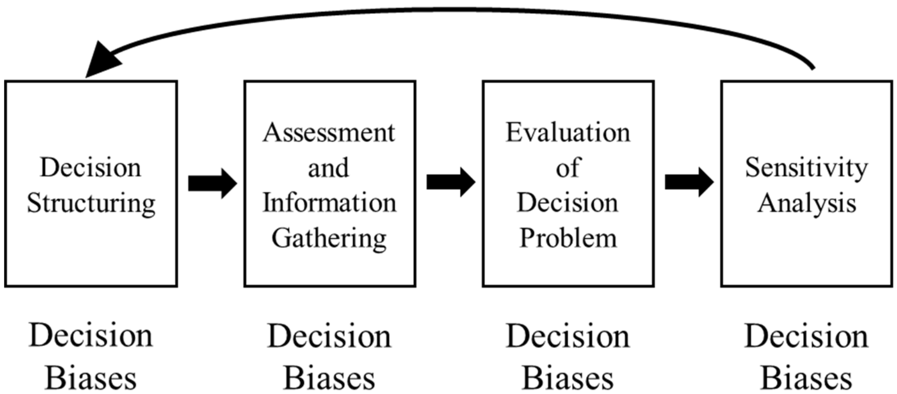
   b. assigning values to the various possible consequences of the available alternatives.

3. *Evaluation of the decision problem:* Analyze the information provided in the first two steps to determine which alternatives to undertake.

4. *Sensitivity analysis*: Determine if the decision is sensitive to changes in valuations of outcomes, probabilities, or other assumptions you have made.

Professor George Wu prepared the original version of this note, "Decision Analysis," HBS No. 894-004. This version was prepared jointly by Professor George Wu (University of Chicago) and HBS Professor Kathleen McGinn for the basis of class discussion.

Figure 1



Source: Casewriter.

Each step of this four-stage process yields insights into the decision problem. If the insights gained at any stage are sufficient to allow you to make a decision, then there is no need to proceed further. On the other hand, the process is often *iterative*: you might return to a previous step in the process if an insight leads you to consider another alternative or question an assumption.

Many believe, falsely, that decision analysis is merely a set of mechanical techniques that spits out "the best option" if applied properly. This characterization sells short both decision analysis and the manager as decision maker. The technical aspects of the four steps outlined above are demanding in themselves, but sound decision making requires much more than technical command of decision analysis. We emphasize throughout this note that a wise decision requires judgment and creativity *as well as* technical proficiency. Furthermore, following these four steps will not ensure a good outcome, or even a good decision. Lurking in the background at every stage in the process are *decision biases*, pitfalls that managers face in making sound choices. As Nobel laureate Daniel Kahneman detailed in his book, *Thinking, Fast and Slow*[1], decision biases can distort the decision process and lead to poor decisions.

A Simple Decision Problem

Consider the following simplified decision problem:

> Sarah Chang is the owner of a small electronics company. The company is working on technology to create a prototype of a new timing system for track events that would be superior to any product currently on the market, and hopes the system will be adopted for the upcoming Summer Olympics. A proposal and working prototype are due to the Olympic Committee in six months. If her R&D team succeeds in developing the prototype technology within the next six months, there is an excellent chance that Chang's company will win the $10,000,000 Olympic contract. However, progress in research and development has been slow, and Chang is unsure about whether her company will be able to produce the prototype technology in time.

[1] Kahneman, D. (2011). *Thinking, Fast and Slow*. New York: Farrar, Straus and Giroux.

> If she continues research on the new system, the company must invest $2,000,000 in additional R&D expenses. After development, producing the prototype is straight-forward at an estimated cost of $500,000. If the prototype is successful and Chang's new timing system is selected for the Olympic contract, production costs will be $1,500,000. Chang must decide whether or not to continue developing the new timing system.

Qualitative Structuring

Many of us begin attacking a decision problem before we even understand what the decision is all about. We start deciding before we know all of the critical features of the decision problem, what alternatives are available, and what criteria we will use to choose among alternatives. Asking a few simple questions upfront can provide a surprising amount of clarity. In particular, decision makers should begin by asking themselves the following three questions:

- What are my *alternatives*?
- What are the critical *uncertainties* that affect the outcomes of my decisions?
- What *objectives* am I trying to achieve in making a decision? What decision *criteria* will I use to choose among the competing alternatives?

Alternatives, uncertainties, and decision objectives are three basic components of virtually every decision problem. We will look at each of these three aspects from Chang's point of view.

Alternatives

Chang should first identify what options are available to her. It is six months prior to the proposal date. What can Chang do? First, Chang can **abandon** the project altogether, thereby avoiding the risks of failing to develop the technology necessary to produce an acceptable prototype. Or, Chang can **continue** to invest in the project. If she continues with the project, at some juncture she will need to decide **whether to create the prototype and make a proposal**.

Uncertainties

We often have to make decisions without knowing exactly what will happen tomorrow. Nevertheless, a wise decision maker must consider the major uncertainties and make judgments about how likely these uncertain events are to occur. One way to elicit a list of critical uncertainties is to imagine a clairvoyant, an individual who could look into the future and indicate perfectly what will happen if a given course of action is taken. Imagine that a clairvoyant will allow Chang to ask a few questions. What questions should Chang ask that might help her choose wisely? First, she may begin: "Will R&D succeed in developing the prototype technology?" Second, she might ask, "If R&D succeeds and we submit a prototype and proposal, will we win the contract?" Of course, there are many other uncertainties that Chang might wish to have resolved, such as the success of other company projects or whether a venture capitalist might be interested in investing in her firm if the timing system is adopted for the Olympics. However, Chang need not consider these factors if they do not bear on her decision of whether to abandon or continue the Olympic project.

Objectives

We make decisions as a means of achieving objectives. Thus, good decision making requires a clear understanding of our objectives. What are Chang's objectives? First and most obvious, she wishes for her company to make money. It is easy to stop here and omit other legitimate objectives Chang may have, such as to attract venture capitalist money, to enhance her company's reputation, etc. These objectives should be considered in the analysis if they are important and if the choices she might make could have an impact on achieving these objectives.

It is often appropriate to consider a unitary objective, such as ***maximize net cash flow***. When maximizing net cash flow, you choose the alternative that yields the largest positive cash flow or smallest negative cash flow. Applying this criterion to a choice between $10 and $20 is straightforward. However, what if the choice is between $25 for sure and a 50% chance at $60? Because a 50% chance at $60 has two possible outcomes, $0 and $60, the criterion of maximizing net cash flow does not help.

How do we value a 50% chance at $60? Clearly, this option is worth less than $60, the best outcome. It is also worth more than $0, the worst outcome. Since the probability of receiving $60 is .50 and the probability of receiving $0 is .50, the value of a 50% chance at $60 might be $30, i.e., .5($0) + .5($60), or halfway between $0 and $60. (Similarly, the value of a 25% chance at $60 might be $15, i.e., .75($0) + .25($60), or one-quarter of the way from $0 to $60).

In our example, $30 is the ***expected monetary value (EMV)*** of a 50% chance at $60. EMV is determined by multiplying each outcome by the probability of that outcome occurring, and then summing these products. As another example, the EMV of a 30% chance at $50 and a 70% chance at $100 is

$$.30(\$50) + .70(\$100) = \$85.$$

It is not always appropriate to use EMV without some adjustment. Some individuals will value a 50% chance at $60 at less than its EMV of $30 because they dislike taking risks or are *risk averse*. Similarly, a *risk seeking* individual likes risk and prefer a 50% chance at $60 over $30 for sure. An individual who views a 50% chance at $60 as equivalent to exactly $30 is *risk neutral*.

A corporation with limited capital might reject a positive EMV alternative if the chance of a loss is too high, or if the loss would put the firm in an untenable situation in terms of available capital. Thus, Chang might wish to consider risk explicitly if her company is perilously close to bankruptcy. Even so, maximizing EMV is a reasonable criterion for a surprisingly large number of decision problems. It should be used when the stakes are small compared to the resources of the company or the individual decision maker and when money is the primary concern. Even when a decision maker wants her decision to reflect risk aversion or non-monetary objectives such as enhancing company reputation, EMV can be used as a benchmark. Taking a first cut using EMV might provide a great deal of insight into the decision problem. The decision maker might then take a more refined cut that incorporates risk attitudes and non-monetary objectives.

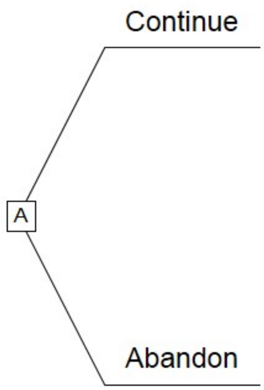
Thus, in this example, we make the *initial* simplifying assumption that Chang wishes to maximize EMV.

Decision Trees, Alternatives, and Risks

In the next stage of decision analysis, Chang should quantify the options available to her and the uncertainties she faces. We represent the chronological sequence of these options and uncertain events in a ***decision tree***, which can be thought of as a roadmap of the decision problem.

It is six months prior to the proposal date. What can Chang do? As noted earlier, Chang can abandon the project altogether, thereby avoiding the risks of failing to develop the technology to produce an acceptable prototype. On the other hand, Chang can continue to invest in the project. If these are the two possible options available to Chang, her decision tree begins with the two branches shown in **Figure 2**. Note that *a decision is represented in a decision tree by a square or **decision node**.*

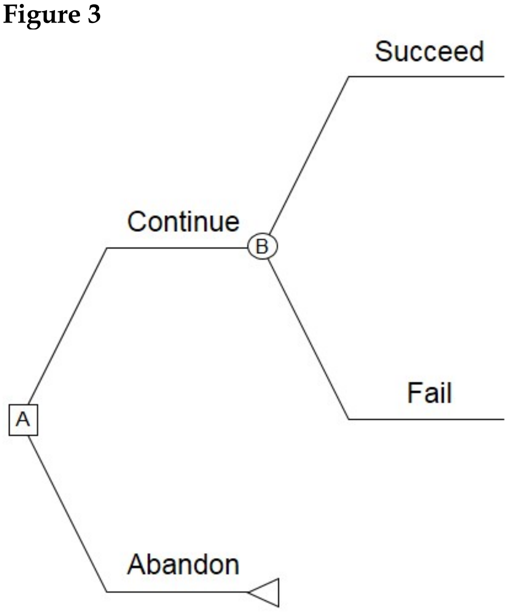
Figure 2



Source: Casewriter.

At this point, Chang should ask herself, "Then what?" If Chang abandons the investment, then she is done; she does not need to consider this path any further. On the other hand, what might happen if Chang decides to continue with the project? In the next six months, either Chang's engineers will succeed or fail in their effort to develop the prototype technology. Chang is unsure which of the two possible events will occur. *In a decision tree, we represent an uncertain event with a circle or **chance node**. The **endpoints** or final outcomes of a decision are denoted by a triangle.* Chang's decision tree so far is shown in **Figure 3**.

Figure 3

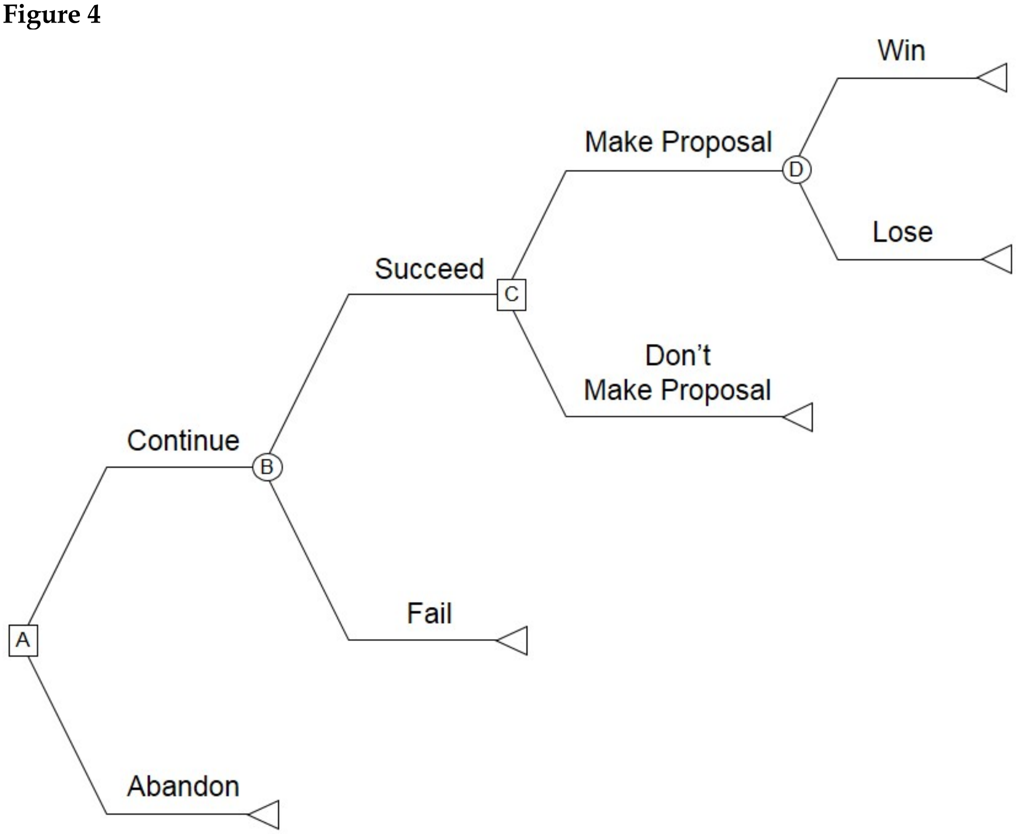


Source: Casewriter.

Chang should continue to ask herself, "Then what?" What could happen in the event of technological success and in the event of technological failure? First, suppose that Chang's engineers develop the prototype technology in time. Chang must then decide whether to make a proposal which requires the production of a prototype. Since it costs $500,000 to produce a prototype, it is not obvious whether or not Chang should submit a proposal. If Chang is unsure of whether an option is a good one, she should include it in the decision tree. If the alternative proves to be worse than another option, it will be eliminated at a later stage in the analysis.

If she submits a proposal, she may either win or lose the contract (**Figure 4**). Of course, winning or losing the contract is an uncertain event. If she does not submit a proposal, there is nothing further to consider.

Figure 4



Source: Casewriter.

The process of Chang asking "Then what?" has produced a concise description of her decision problem. The decision tree is a chronological depiction of the alternatives immediately available to Chang, as well as future alternatives and uncertainties. The decision tree provides immense clarity about the decision problem—perhaps providing enough insight that it becomes clear to the decision maker which alternative she should undertake. In this problem, if the chance of technological success is low, the cost of development high, and the rewards of winning the contract low, Chang might conclude that she should abandon the project. Problems that are not so clear cut require a more complete analysis; the decision maker must assess the likelihood of the uncertain events and estimate the value of the possible outcomes.

In this example, the set of options and uncertainties is fairly small. In many real world problems, however, the process of depicting a decision tree requires more creativity. Even in this simple problem, the analysis could easily be enhanced by considering additional alternatives: for example, investing $3,000,000 in developing an even more advanced system instead of $2,000,000, abandoning the effort after three months, etc. It is up to the manager to use ingenuity and creativity to ensure that the decision tree captures all the reasonable options available. Creative decision makers can often conceive of alternatives others would overlook. Often the process of capturing the decision problem as a decision tree will suggest alternatives that might not have been imagined otherwise.

The Uncertain Future

In almost every important decision, the outcome of the decision depends not only on the alternatives the manager chooses, but also on external events that are not under the manager's control. For example, an investor's return depends on which stocks she owns (her decision) and whether these stocks increase or decrease in value (an external event); a farmer's annual income depends on the crops planted (his decision) and the weather and market price for the crops (external events); and a publisher's profits depends on which books she publishes and how much she spends in promotion (her decisions) and consumer demand for books and the state of the economy (external events).

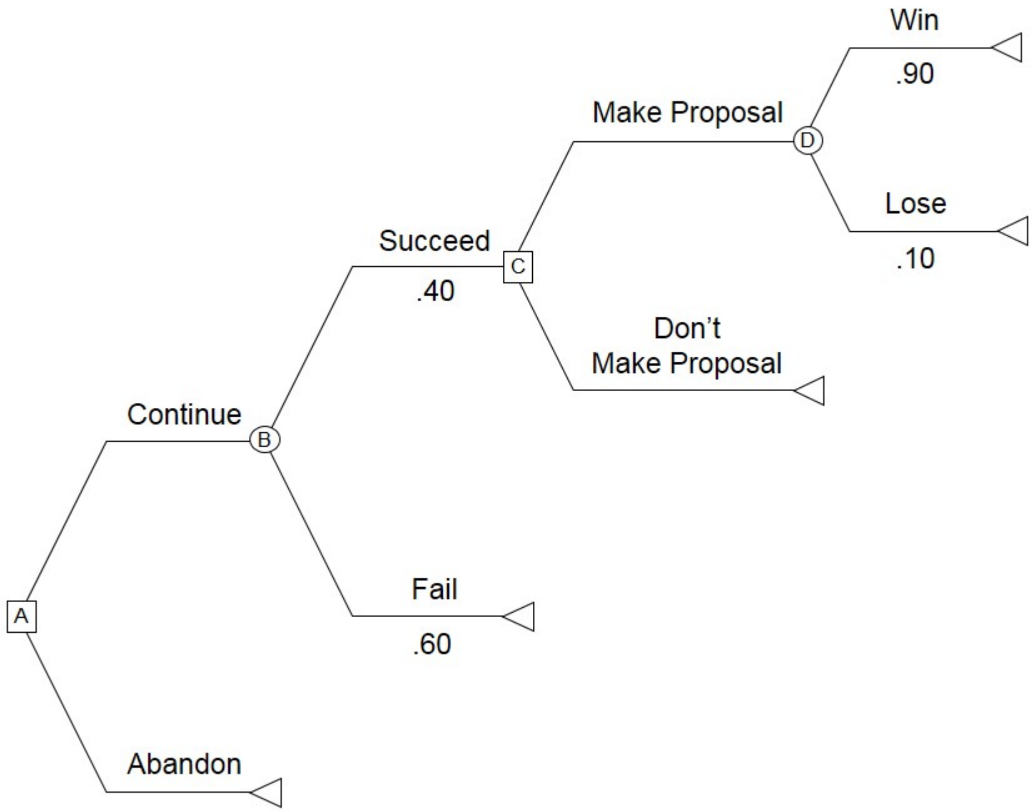
Probabilities measure the likelihood of uncertain events. If the probability of an event is set to 0, the decision maker is saying that the event is impossible. If an event will happen for certain, the probability of that event is 1. Probabilities provide us with a precise numerical language for communicating judgments about the uncertain future. Often you will hear statements like: "I think that there is a *pretty good* chance that our sales will be at an all-time high this year," or "It is *unlikely* that our competitor will change his price in the near future," or even "I am *quite unsure* about how the government will act on this issue." These phrases attempt to communicate a judgment about the uncertain future in a language that is imprecise at best. In contrast, probabilities require the decision maker to be explicit in her pronouncements; instead of merely saying that there is a "pretty good" chance, she must give her opinion of *how* good a chance.

In our example, Chang must estimate the probability of developing a successful technology in time to submit a proposal. Naturally, Chang will want to obtain as much knowledge about the problem as possible by conducting statistical analysis, talking to her engineers, reviewing past projects, and perhaps consulting outside experts. This research forms the input for her probability judgments.

Let us assume that Chang does her research and concludes that the probability of successfully developing the technology in six months is 40%. Thus the chance of technological failure is 60%. In addition, Chang believes there is 90% chance that she will win the contract if the company successfully develops the technology and then submits a proposal and prototype. These probabilities are reflected in the decision tree depicted in **Figure 5**.

Although these best managerial judgments are necessarily subjective and hence not "right" or "wrong," they are not arbitrary. While Chang cannot see into the future, she can use the data from all of her past experience with product development and the expertise of her research scientists to estimate the likelihood of future events. The probabilities reflect Chang's informed judgments about the likelihood of various events.

Figure 5



Source: Casewriter.

Endpoints and Monetary Consequences

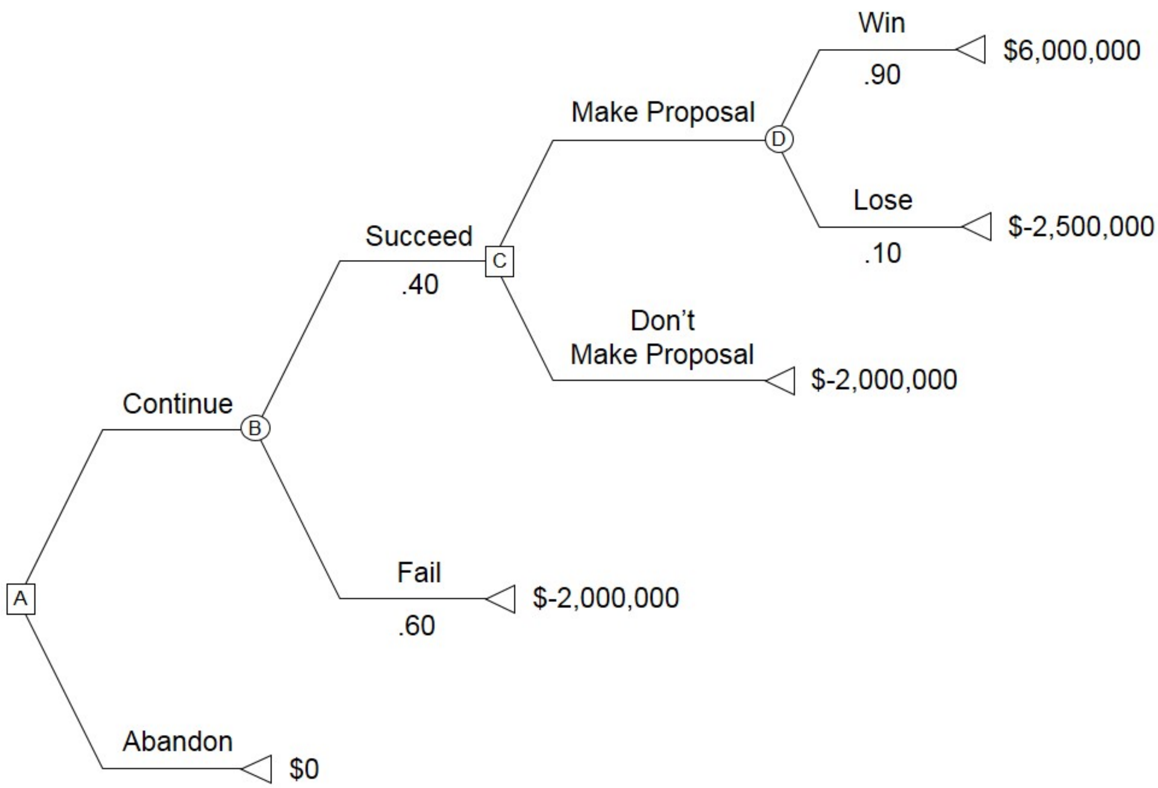
Even with the decision tree in **Figure 5**, Chang could not make a fully informed decision unless she knew the value of the various outcomes. For example, how much better off is she winning the contract than failing to win it? In this stage of the process, Chang must evaluate each terminal point in the decision tree. For each path in the decision tree, a unique set of choices and events, called a ***scenario***, has transpired. For example, in one scenario, Chang decides to continue with the project, her engineers are successful in developing the new technology, the company submits a prototype and proposal, and is awarded the contract. Presumably this is the best scenario of all. But how good is it?

Recall that Chang wants to maximize the expected monetary cash flow. Thus Chang must evaluate the net cash flow that results at each ***endpoint***. In this step, she should identify all of the relevant costs incurred in the various activities, as well as the relevant revenues. If she wins the contract, then Chang will have expended $2,000,000 in R&D costs, $500,000 in developing the prototype, and $1,500,000 in producing the final product. Thus the total costs to her will be $4,000,000. Since she will have won a contract worth $10 million, the net cash flow will be $6,000,000.[2] If she develops the technology, makes

[2] A more detailed analysis would reflect the differential timing of the cash flows and the time value of money. Thus, the various cash flows would be expressed in terms of their ***net present value***. We will not worry about these details in this note.

a proposal, but is not awarded the contract, then the net cash flow will be $-2,500,000 (a loss reflecting the R&D costs plus the cost of developing the prototype). The other cash flows can be calculated by subtracting the relevant costs from the relevant revenues. They are shown for each scenario in **Figure 6**.

Figure 6

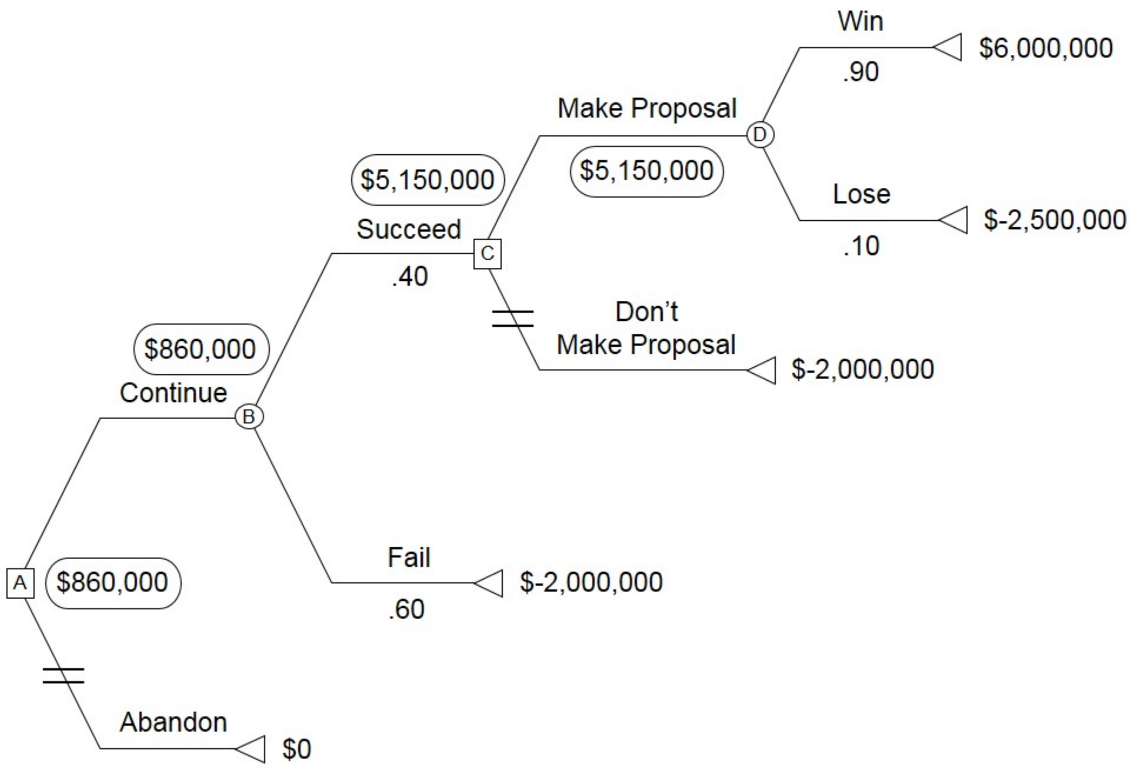


Source: Casewriter.

What Is Best: Folding Back the Tree

At this point, Chang has structured the problem and used her judgment to assess the critical uncertainties and to evaluate the endpoints. Now she is ready to combine these judgments to determine the best course of action. We will start at the endpoints of the decision tree and work our way backwards to the present. Let us assume that Chang decided to continue the venture, that her engineers were successful in developing the prototype technology, and that she went ahead with the proposal. Thus she is at node (D) in the decision tree. At this juncture, either she will win or lose the contract. Recall that Chang wants to maximize EMV. If we weight the "Win" and "Lose" outcomes by their respective probabilities, we find that the EMV for node (D) is .90($6,000,000) + .10($-2,500,000), or $5,150,000. Thus we replace the uncertain event at node (D) with its EMV, $5,150,000 (**Figure 7**).

Figure 7



Source: Casewriter.

At node (C), Chang has a decision of whether or not to make a proposal. If she makes the proposal then she can “expect” $5,150,000. However, if Chang does not make the proposal then she will lose the $2,000,000 she expended in development costs. Clearly, she should make the proposal, also spending $500,000 to create a working prototype. Thus at node (C), we substitute the EMV of the better of the two decisions, “Make proposal.” We can “prune” the inferior option, “Don’t Make Proposal,” from the decision tree. *A pruned, i.e., rejected, inferior option is denoted by two short parallel lines.*

We now have a procedure for analyzing the entire decision tree. Start at the endpoints of the decision tree, working backwards toward the beginning of the tree.

- Replace each chance node with that chance node’s EMV (multiply the probability of each event by that event’s EMV and then sum up)
- Replace each decision node with the highest EMV of any of the alternatives

We call this process of simplifying the decision tree ***folding back the tree*** or ***backwards induction***. Chang can decide what to do initially at decision node (A), because she knows what she would choose if she were at decision node (C).

If we continue this process to the beginning of the tree, we find that Chang should continue investing in research and development and then create a prototype and make a proposal if her company succeeds in developing the technology. The EMV of this strategy is $860,000. **Figure 7** depicts the complete analysis.

Consequences Not Contained in the Cash Flows

In most decisions, there are consequences that are not purely monetary. In these situations the non-monetary consequences should be evaluated and included in the analysis. In this example, we have simplified the situation by assuming that developing the new timing system technology is valuable only because it increases the probability of winning the contract. However, having the technology in hand will often have considerable value outside this simple context: the prototype technology may open doors for other projects in the future, may enhance the reputation of Chang's company, etc. These benefits can be quite substantial and should be reflected in the analysis.

In general, if the manager believes that the various endpoints on her decision tree leave her with different prospects for the future or achieve different non-monetary objectives, she should assess the value of these future differences and add them to the cash flows. Thus, the analysis should reflect any differences in customer relations, employee morale, equipment, inventories, reputation, etc.

In our simple example, continuing to invest is the best initial choice. If winning the Olympic contract improves Chang's chances of attracting venture capital or enhances the company's reputation, then these objectives should be included in the analysis. However, here, no additional analysis is necessary: it is easy to see that these factors just strengthen the argument for continuing investment in R&D.

Sensitivity Analysis

In a previous section, we discussed how Chang might think about the judgmental probabilities. She may indicate that .90 is the probability of winning the contract if she has the new technology, but this judgment might be based on relatively little knowledge or experience. Chang might not feel particularly comfortable about investing such a large sum of money in this project without giving some more thought to the probability.

If Chang spent more time thinking about the chance of winning, perhaps reflecting on what her competitors might be up to, then the probability she assigns to winning might change. On the one hand, if, after further reflection, she decided that the probability of winning was actually higher than 90%, the decision to continue the project would be unaffected. On the other hand, the probability of winning might drop. How low could the probability fall before "Continue" becomes worse than "Abandon"? First, Chang might choose some lower probability of winning, say .40 and fold back the tree with this new probability. In this case, she would find that the EMV of "Continue" has become negative, $-840,000. After some trial and error or some simple algebra, Chang would determine that the EMV of "Continue" is positive when the probability of winning is greater than .647; it is negative when the probability is less than .647. Chang might not be able to state precisely the probability of winning, but she might feel confident that the probability is higher than .647. In this case, it is not worth investing her time refining her original probability assessment, because further reflection on the probability of winning would not change her decision to continue with the project.

The reasoning used in ***sensitivity analysis*** can also be applied to other judgments a manager might make such as the value of company reputation or employee morale. Recall that we emphasized that *decision analysis is an iterative process*. In the first stage, a decision maker may make a tentative assessment or valuation or a simplifying assumption in order to reach a preliminary conclusion about which alternatives to undertake. For example, Chang chose to ignore the non-monetary benefits of having the prototype technology. After folding back the tree, she should determine whether her decision to continue investing is sensitive to any of the tentative judgments she made earlier. In this case, any benefits of developing the prototype technology only reinforce her decision to continue the project. On the other hand, if Chang finds that her decision is very sensitive to some other judgment, she may want to invest some resources refining this judgment. Thus a smart decision maker can use sensitivity analysis to identify which judgments need to be considered more carefully and which do not.

Decision Biases

At each step in the process, the manager might make an error in judgment. Some errors in decision making, ***decision biases***, are systematic. In the structuring phase, for example, managers often focus on the "wrong" problem. A manager might frame the decision as a tactical choice, when it is in fact a "strategic" decision. Or a production-oriented company might tend to view all of their decisions through an engineering lens, even though such a lens may not always be appropriate. Looking at the world in such a way might focus attention exclusively on efficiency, neglecting concerns such as meeting the needs of the consumer.

Managers also are not particularly good at estimating probabilities. They tend to be wildly overconfident in their judgments. When a product manager says that there is only a 10% chance that demand might be as low as 100,000 units, the actual probability might be 30% to 50%. In addition, we tend to be biased in how we weigh evidence, tending to overweight recent and salient evidence and underweight historical information. For example, Chang's estimate of R&D's success in developing the prototype might be largely based upon the most recent R&D report. She might neglect the stack of historical R&D reports sitting in her file cabinet, however relevant these reports might be.

Epilogue

Chang's decision problem was relatively simple. Most managerial decision problems are more complicated. The sheer size of these problems can often paralyze a decision maker. However, decision analysis offers a systematic approach to decision making, breaking down the decision problem into smaller, more easily digestible pieces. At each step in the process—structuring, assessment and evaluation, analysis, and sensitivity analysis—the manager can gain insight into the decision problem. The end result will be better decisions.