Naval War College Review

Volume 27
Number 4 *July-August*

Article 6

1974

Decision Analysis: Toward Better Naval Management Decisions

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The ideal at which we should aim . . . is a way of making our choices . . . rationally and with a maximum of clarity about the values we seek. We should seek this rationality if for no other reason than the logic of making the most of whatever power our knowledge gives us to get what we want.

Roger Hilsman

DECISION ANALYSIS:

TOWARD BETTER NAVAL MANAGEMENT DECISIONS*

An article prepared

by

Lieutenant N. Clark Williams, U.S. Navy

Introduction

Making decisions in the face of uncertainty is an integral part of our lives. We must act without knowing the consequences that will result from the action. This uncomfortable situation is particularly acute for the Navy's civilian and military managers who must make far-reaching decisions in areas of responsibility that include force planning, military operations, financial management, defense procurement, research and development, and personnel policies.

It is instructive to observe how relatively trivial most significant decision problems become if uncertainty is removed. For example, consider the ease of making a critical decision in developing a new weapon system if the decisionmaker could predict with certainty the characteristics of the target types to be encountered, the performance of the system, the physical environment in which the system would have to function, the total system cost, and so forth.

But uncertainty is not the only ingredient that can complicate the decisionmaking process. Decisionmaking also requires the study of values: a determination of the trade-offs between monetary and nonmonetary quantities

*The author is grateful to Dr. James E. Matheson, Director of the Decision Analysis Department, Stanford Research Institute, Menlo Park, Calif., and to Dr. Ronald A. Howard, Professor of Engineering-Economic Systems at Stanford University, Stanford Calif., for their invaluable contributions to this paper. Further acknowledgment is made to Lt. Kevin J. Reardon, USN, for his critical review and several valuable suggestions to this paper.

and an evaluation of the time and risk preferences of the decisionmaker. (The author provides an applicatory business case study of decision analysis in appendix I.)

The purpose of this paper is twofold. First, it suggests a philosophy and a language that should underlie any decisionmaking process. Second, it outlines a formal procedure for the decision problems that confront Navy top management. The language, the philosophy, and the procedure are derived from a new discipline called decision analysis—a term that is used to describe a body of knowledge and professional practice concerned with providing a rational basis for decisionmaking.

Decision analysis is the outgrowth of two earlier fields, systems analysis and decision theory. Systems analysis is a branch of engineering whose strength is consideration of the complex and dynamic aspects of our environment, while decision theory is concerned with how to be rational in very simple but uncertain situations. Their concepts have been combined to provide a single discipline that has the capability to handle simultaneously complexity, dynamic effects, and uncertainty. Decision analysis permits mathematical modeling of a decision, computational implementation of the model, and quantitative evaluation of the various alternative courses of action. But perhaps the most important benefit derived from decision analysis is that it can increase our understanding of the decision process.

Let us be clear at the outset that decision analysis is a normative, rather than a descriptive, approach to decision problems. The decision analyst is not interested in describing how decisionmakers currently make decisions; rather he tries to show how a person subscribing to certain logical rules would make these decisions in order to maximize attainment of his objectives. The decision procedures are derived from logic and from the desires of the decisionmaker, and in this sense they are prescriptive.

Some Preliminary Definitions

Before we discuss decisionmaking, we must define a decision. For the purpose of this paper a decision is considered to be an irrevocable allocation of resources, in the sense that additional resources, perhaps prohibitive in amount, would be required to change the allocation. A decision, then, is not a mental commitment to carry out some course of action; it is the actual embarkation on a course of action—a de facto allocation of time, money, or some other resource. Some decisions are inherently irrevocable, such as a decision to employ a nuclear weapon; others are essentially irrevocable, such as a decision to build a particular class of ship.

We must also define a decisionmaker: an individual or organizational entity who has the power to commit the resources of an organization. It is important to distinguish advisory individuals or bodies from those with the power to commit the organization. An obvious example of an advisory body in the Navy is, of course, OP-96, the Systems Analysis Division in the Office of the Chief of Naval Operations. OP-96, or some other group, may perform study after study advocating or decrying a certain course of action, but until resources are committed, no decision has been made.

A basic concept in decision analysis is the distinction between a good decision and a good outcome. We define a good decision to be a logical decision, one that is consistent with the information, values, and preferences of the decisionmaker. A good outcome is one that is profitable or otherwise highly valued. In other words, a good outcome is one that we wish would happen. Hopefully, by making good decisions in all the situations that face us, we will ensure as high a percentage of good outcomes as is possible. Bear in mind, however, that a good decision is no guarantee of a good outcome. In fact, we may be disappointed to find that a good decision has produced a bad outcome, or we may be dismayed to learn that someone who has made what we consider to be a bad decision has achieved a good outcome.

Another issue lies just below the surface of the discussion in the preceding paragraph. Should Navy decisionmakers be rewarded on the basis of the quality of the decisions they make or on the basis of the outcomes they achieve? Some very compelling arguments can be offered for rewarding people on the basis of the quality of their decisions, but the world in which naval officers operate is one that rewards individuals according to the outcomes they experience. We deliberately sidestep this interesting issue here by asserting that, even though the organization to which we belong is outcome-oriented, there is no better alternative in the pursuit of good outcomes than to make good decisions—pending the arrival of someone who can foretell the future.

Decision Analysis as a Language and a Philosophy

The formalism of decision analysis serves both as a language for describing decision problems and as a philosophical guide to their solution. The existence of the language gives us a way to talk about the process of decisionmaking even if we never do a single computation. When we do put pencil to paper, the language permits us to specify with precision the multitude of factors that influence a decision.

The most important feature of the language is the use of probability theory to represent the uncertainty that inevitably permeates a decision problem. Virtually all the theorists are in agreement on the proper use of the calculus of probability, but considerable disagreement exists on the use of its results. For reasons we do not explore here, many people interpret probability as a measure of the state of knowledge about a phenomenon rather than as a measure of a physical property of the phenomenon that can be estimated by repeated measurements. The operational justification for this interpretation, called the subjective interpretation, can be simple: Suppose that I am about to flip a fair coin, after which I will observe the results, but you will not. Prior to the coin toss, you and I, being reasonable naval officers, agree that the probability of "heads" is one-half. However, when I flip the coin and then observe the results, the probability of heads from my point of view will change to either 0 (heads did not occur) or 1 (heads did occur), while you will continue to assign a probability of one-half to the event that a head has occurred because you are not yet privy to the outcome. What has changed? Certainly not the physical characteristics of the coin. It is rather that my state of information about the coin has changed, while yours has not.

The subjective interpretation of probability is fundamental to the decision analysis philosophy because it permits us to specify our degree of belief about the occurrence of any uncertain event. Rather than saying, "There is some chance of the likelihood that a submarine might penetrate a carrier's ASW screen" or making an equivalent ambiguous statement, we can speak directly of the probability that a submarine will penetrate the screen. There is no need for vagueness in a language that describes uncertainty. And while you may need an expert to carry out complex probabilistic manipulations, you certainly do not need to be an expert to think in probabilistic terms; most managers easily acquire the rudiments.

Decision analysis can also make a major contribution to the understanding of decision problems by providing a language and a philosophy for treating values and preferences. Values refer to the desirability of outcomes; preferences refer to the attitudes of the decisionmaker toward postponement of the outcomes he will receive or uncertainty as to what those outcomes will be. Placing values and preferences in unambiguous terms is as unusual in current Navy decisionmaking as is the use of direct probability assignments. Yet both must be done if the decision analysis procedure is to be used to full advantage.

An important benefit of thinking in the unambiguous terms of probabilities, values, and preferences is the resolution of individual differences that often arise between protagonists. Two people who differ over the best alternative may find their disagreements in the areas of probability assignment, value, or preference. Thus, two men who are equally willing to take a risk may disagree because they assign different probabilities to various outcomes, or two men who assign the same probability to the outcomes may differ in their aversion to risk. It is unlikely that the nature of the disagreement will emerge and be understood without the formal language. More likely, emotive epithets such as "shortsighted carrier advocate," "old-school conservative," or "tunnel-visioned submarine proponent" will preclude any communication at all.

The decision analyst must play a detached role in illuminating the decision problem if he is to resolve differences. He, as well as the organization he represents, must be impartial, never committing himself to any alternative, but rather showing how new information or changes in preference affect the desirability of available alternatives. The effectiveness and the long-run credibility of the decision analyst depend as much on his emotional detachment and his intellectual honesty as on his knowledge of formal tools.

Decision analysis, as we shall see, is more than a language and a philosophy, but the explicit recognition of uncertainty and value questions in management discussions will in itself do much to improve the decisionmaking process. In fact, it appears that organizations that have begun to think about decisions in this manner do not, indeed cannot, revert to their old ways of thinking. Now let us look at decision analysis as a logical and quantitative procedure—an actual way to make a decision.

Decision Analysis as a Procedure

As we have intimated, decision analysis implies a how-to-do-it procedure for progressively analyzing a decision problem. The procedure is embodied in what is called the decision analysis cycle. Figure 1 views the decision analysis cycle as comprising three major phases: the deterministic, probabilistic, and informational phases.

In the first or deterministic phase, variables affecting the decision are defined, their relationships are characterized in formal models, and values are assigned to possible outcomes. The importance of the variables is measured through sensitivity analysis without any consideration of uncertainty. The complexity of the formal models in the deterministic phase will differ from problem to problem: from sketched decision trees to large systems of interconnected computer programs.

The second or probabilistic phase assigns probability distributions to the important input variables and derives a corresponding probability distribution on the outcomes. The decision analysis methods supplement the causal models of the deterministic phase by using probability to describe what is not known. This phase also introduces the assignment of risk preference, which

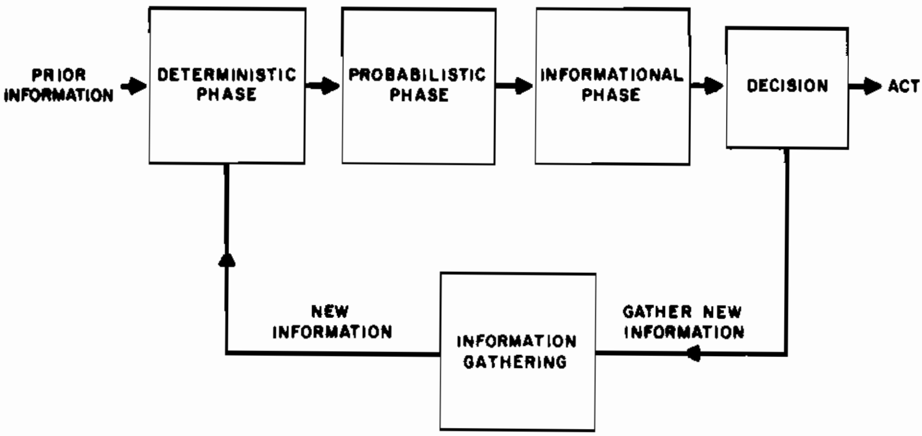

Fig. 1—The Decision Analysis Cycle

provides the best solution to the problem in view of the decisionmaker's tolerance for uncertainty.

The third or informational phase determines the economic value of additional information by calculating the worth of eliminating uncertainty in each of the important variables in the problem. The value of additional information can then be compared with the cost of obtaining it.

If it turns out that value minus cost is nonnegative, the decisionmaker should gather the information rather than make the primary decision at this time. The new information that comes from the information-gathering program often changes the model and the probability assignments on the important variables, so the decisionmaker and the decision analyst must return to the deterministic phase and proceed again through the analysis cycle. Fortunately, the additional work required to incorporate the modifications should be slight, and computation should be rapid. Eventually, the value of gathering new information will be less than the cost of doing so, and the decision to act will be made.

The decision analysis cycle is not an inviolable method of attacking a problem, but it is a means of ensuring that the essential steps have been considered. With this point in mind, we now examine the steps required in each phase.

The Deterministic Phase. The deterministic phase is, in many respects, a systems analysis of the decision problem, because this phase is concerned primarily with representing the various relationships of the problem in formal, mathematical terms, a process called modeling. The major steps that make up the deterministic phase appear in figure 2 (the reader may find it useful to refer to that figure as we discuss the deterministic phase).

The first step in any decision analysis is to determine just what decision must be made. Many decisionmakers have found that what appeared at the outset to be a decision problem turned out to be no more than a worry about circumstances beyond their control. Still others have discovered that their decision problems were not at all what they had first imagined them to be.

The next step is to identify the alternative courses of action that are available to the decisionmaker. The finding of new alternatives is perhaps the most inventive part of decision analysis, and on more than one occasion the difficulty of a decision problem has

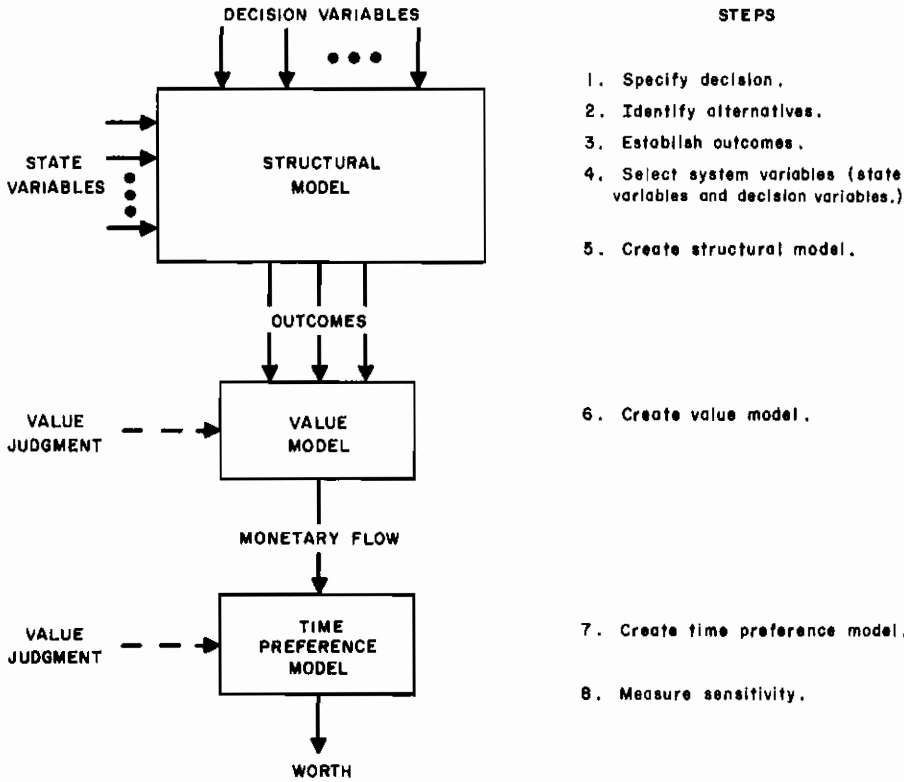

Fig. 2—The Deterministic Phase of the Decision Analysis Cycle

disappeared when a new alternative has been uncovered. Here the decision analysis formalism calls for "sparks of creativity."[1] Unfortunately, decision analysis does not suggest to the decisionmaker how these sparks can be supplied, but at least it shows where and how they can be used.

The third step is to specify the outcomes that the set of alternatives could produce. Outcomes are the events following the decision that determine the ultimate desirability of the whole issue under consideration by the decisionmaker; they represent the answer to the question, "What might happen?" In a weapon system acquisition, for example, the outcomes might be specified by total procurement cost, numbers of jobs created or destroyed in industry, system reliability, destructive capability, battle deaths, support requirements, and so forth. Here again is a need for creativity, for recognizing what might happen in the future that would be relevant to the actions the decisionmaker is contemplating.

The deterministic phase continues with the selection of all the variables upon which the outcomes depend; these are called system variables. We can think of this selection process by imagining we have a crystal ball that will answer any numerical questions about the decision problem (except, of course, which alternative to select!). We could simply ask it questions about the outcome variables directly, thereby making them the only system variables in the problem. However, outcome variables are often difficult to think about directly, so typically we would choose to relate the outcome variables to others easier to comprehend.

Next, the system variables are divided into two categories: decision variables and state variables. The system variables that are under the control of the decisionmaker are called decision variables; those determined by the environment are called state variables. For example, if we were considering building a new class of submarines, both the armament and the composition of the communications suit would be decision variables; the cost of a new hull material and the radiated noise level of any particular ship configuration might be state variables. The distinction between the variables to be considered decision variables and those to be considered state variables may sometimes appear to be a difficult one to make. This separation is often achieved by redefining the variables, or the difficulty is resolved by further structuring of the problem.

The fifth step of the deterministic phase is to specify the relationships among the system variables, a process called structuring. This synthesis usually takes the form of a mathematical model (set of equations) that generates a set of outcomes for each value, or setting, of the decision and state variables. How does one build a structural model that accurately captures the essential interdependencies of the problem? That question we cannot answer here. The process can be a long, difficult, and even painful one, but it is imperative that the analyst strive to build a model that depicts the particular situation under consideration. This requirement must be stressed emphatically, because we analysts are often guilty of selecting from our bag of tools the duty MK 1 MOD 0 model, into which we cram a decision problem until it no longer resembles, even remotely, the real world from which it came.

The structural model, then, should provide the decisionmaker with a reasonably accurate representation of the real world, in the sense that it specifies results (outcomes) given the inputs (settings of the decision and state variables). But a set of outcomes can be messy to work with, because it includes all the items, distributed over time, that the decisionmaker said were important to him when he answered the question, "What might happen?" Although in some cases the decision can be reached as a result of ordering outcomes in terms of desirability, most problems of practical interest require a numerical ranking system. There may be many elements of value in an outcome, but the final value assignment to the outcome is a single number. The sixth step is concerned with assigning that number.

The value issue is often confused with the issue of uncertainty, an aspect of the decision model we have not yet considered. In constructing the value model one might say, "Suppose I eliminate all uncertainty and tell you for sure what is going to happen (the role played by the structural model). What would you like? How much more is this outcome worth than that one?" In military problems the value assignment is especially difficult, because it requires measuring the value of a human life and other social values in dollars and cents. These questions of evaluation may be difficult, but logic demands that they be approached directly in monetary terms if monetary resources are to be allocated. We are not talking about the amount for which we are willing to sell something as precious as life—the question is: For what amount are we willing to buy it?[2]

The seventh step in the deterministic phase is to specify the time preference of the decisionmaker. After having established, in the sixth step, a value model to convert all nonmonetary consequences to an equivalent monetary, or cash, flow, the decisionmaker requires a realistic mechanism for describing his time preference. This mechanism, called the time preference model, must reduce a stream of values distributed over time to a single number called worth. What we are really considering is the phenomenon of greed versus impatience or the usual willingness to accept less now instead of more later.

A cautionary note: There is no such thing as a "right" value model or a "right" time preference model. Such models represent the judgment of the individual decisionmaker. However, within the Defense Establishment certain elements of the value and time preference models probably should be universal, i.e., specified for all services and decisionmakers by OSD.

What has been done so far in the deterministic phase? A statement of the decision problem has become a formal description suitable for detailed examination by logical and computational analysis. The decisionmaker's value assignments and his time preference permit rating any outcome that appears, first as a set of values in time and then as a worth. The worth unambiguously ranks any setting of the decision and state variables—the higher the worth, the better the setting of the variables.

The eighth and final step of the deterministic phase is concerned with measuring sensitivities to changes in the values of state variables. The state variables are assigned nominal values (which might be, for instance, estimates of their mean values) and are then swept one by one through their ranges of possible values. The sensitivity analysis will identify the state variables for which the effect on worth is marked. These variables are called crucial variables to emphasize that they have a major effect and that the uncertainty in them deserves special attention. The second phase of the decision analysis cycle, the probabilistic phase, will introduce what is known about the uncertainty in the crucial variables.

In summary, a model was developed and exercised in the deterministic phase, and the crucial variables were identified. Typically, more than one-half of the total professional effort on a decision analysis is expended on the deterministic phase.

The Probabilistic Phase. After the deterministic sensitivity analysis has divided the state variables into crucial and noncrucial classes, the probabilistic phase determines the uncertainty in worth due to the uncertainty in the crucial variables. The steps associated with the probabilistic phase are illustrated in figure 3.

The first step of the probabilistic phase is to specify the uncertainty in the crucial variables. This is accomplished by assigning a probability distribution to each crucial variable. A probability distribution can be assigned by one of several means, including drawing directly upon the expert judgment of the decisionmaker and his designated subordinates.* For example, a recent decision analysis for a large U.S. corporation disclosed that one of the crucial variables was the cost of a new raw material.[3] The best available information about the cost of the raw material consisted of the judgment of the chemists, chemical engineers, and planning and operations specialists of the client.

With the knowledge from the deterministic phase of how the worth depends on the setting of the state variables and the decision variables, it is a straightforward calculation (step two of the probabilistic phase) to determine the probability distribution on worth for the assigned probability distributions on the crucial variables and for any given setting of the decision variables. This probability distribution is called the worth lottery.

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*The interested reader may consult Carl-Azel S. Staël von Holstein and Carl S. Spetzler, "Probability Encoding in Decision Analysis," Paper presented at Joint ORSA-TIMS-AIIE Meeting, Atlantic City, N.J.: 8-10 November 1972.

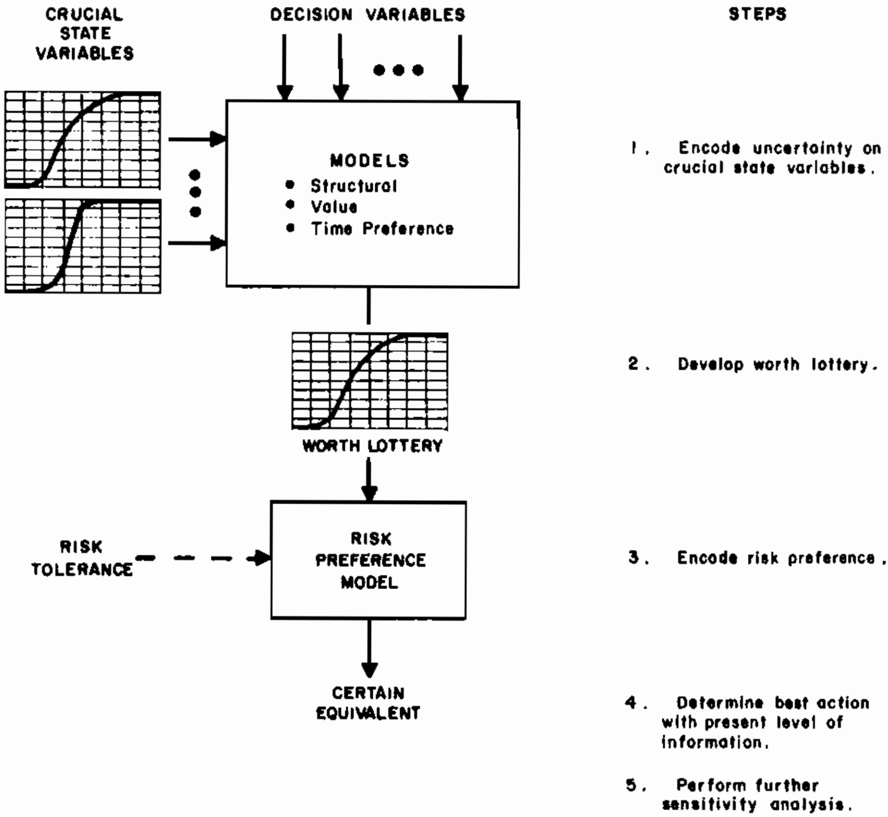

Fig. 3—The Probabilistic Phase of the Decision Analysis Cycle

The format of a worth lottery is detailed in figure 4 where the example curve gives the range of possible values of worth that might be achieved (horizontal scale) and the probability of achieving them (vertical scale).

Of course, a different worth lottery results for each setting of the decision variables as is shown for each of three hypothetical alternative courses of action. The problem now becomes one of choosing between worth lotteries, which obviously could be a difficult job. Fortunately, the decisionmaker's tolerance for taking risks can be encoded, and then each worth lottery can be converted to a single number. The numbers can be used to rank the alternatives.

The process of encoding the decisionmaker's attitude toward risk is the third step of the probabilistic phase. If the decisionmaker agrees to a set of axioms about risk taking, his risk preference can be represented by a utility curve. Such a curve assigns a utility to any value of worth. As a consequence of the risk preference axioms, the decisionmaker's utility rating of any worth lottery can be computed. If one worth lottery has a higher utility rating than another, it must be preferred by the decisionmaker if he is to remain consistent with the axioms. The analyst is not telling the decisionmaker which worth lottery he should prefer, only pointing out to him a way to be consistent with a reasonable set of properties he would like his preferences to possess.

Although the utility rating does serve as a basis for the choice between alternatives, its numerical value has no particular intuitive meaning. Therefore,

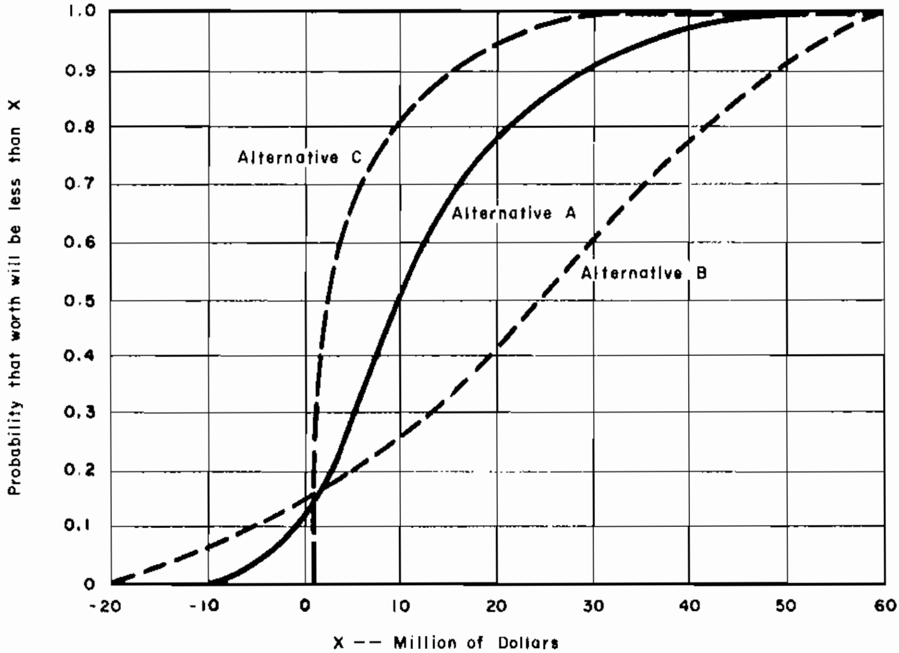

Fig. 4—Worth Lotteries

after computing the utility rating of a worth lottery, the analyst often returns to the utility curve to see what worth corresponds to this rating; this quantity is termed the certain equivalent of the worth lottery. Since almost all utility curves show that utility increases as worth increases, worth lotteries can be ranked in terms of their certain equivalents. The best alternative is the one whose lottery has the highest certain equivalent.

The fourth step of the probabilistic phase is to compute the certain equivalent for each alternative and then choose the one with the highest certain equivalent. The problem structure, the set of alternatives, the probability assignments to the crucial variables, the value assignments, the statement of time preference, and the specification of risk preference have all been combined to indicate the best decision alternative.

But the careful analyst is not yet done, because the introduction of risk preference and probability assignments gives two new points at which to check the sensitivity of the problem. The fifth and final step of the probabilistic phase is twofold: to measure stochastic sensitivity—i.e., to measure the sensitivity of the decision to the probability distributions on the crucial variables—and to measure the sensitivity of the alternatives to changes in the decisionmaker's tolerance for taking risks. Stochastic sensitivity can provide important additional insight to the problem. It might show the need for further structure to allow more effective use of available information, or it might reveal that variables originally thought to be important on the basis of deterministic sensitivity analyses are not so important in the probabilistic environment.

The Informational Phase. The purpose of the informational phase is to place a monetary value on schemes for gathering additional information about crucial variables. This unique feature of decision analysis is intended to provide the decisionmaker with some guidelines in his search for information that can improve his chances for achieving a good outcome.

The first step of the informational phase (see figure 5) is to measure what is called the value of perfect information. The concept is a simple one. Suppose someone exists who knows in advance just what value a particular crucial variable would assume in the decision problem—a person known as a clairvoyant. The value of perfect information is the answer to the question, "How much should the decisionmaker be willing to pay the clairvoyant for his services?"

The clairvoyant is merely a construct, and the value of perfect information is easy to calculate, but the significance of this first step of the informational phase extends well beyond its deceptively simple concept and its minimal computational requirements. The value of information is important because it represents the largest amount that one should pay for the complete elimination of uncertainty regarding a crucial variable. Since most information-gathering activities provide less than perfect information, it is obvious that they should not be pursued when their cost exceeds the value of perfect information. The value of perfect information can also indicate the crucial variables for which it might be worthwhile to look for feasible information-gathering programs; if the value of perfect information on a variable is low, then it will not be worth investigating information-gathering programs for the variable, but if the value of perfect information is high, then one might expend some effort to look for programs which will improve on the decisionmaker's state of information.[4]

Step two of the informational phase is to identify and analyze the information-gathering alternatives available to the decisionmaker. Since information-gathering programs seldom provide perfect information, the criterion for gathering additional information is the value of a given information-gathering experiment. The computational algorithm for determining the value of an information-gathering program is too detailed for this discussion—only the result is of interest: an information-gathering program whose value exceeds

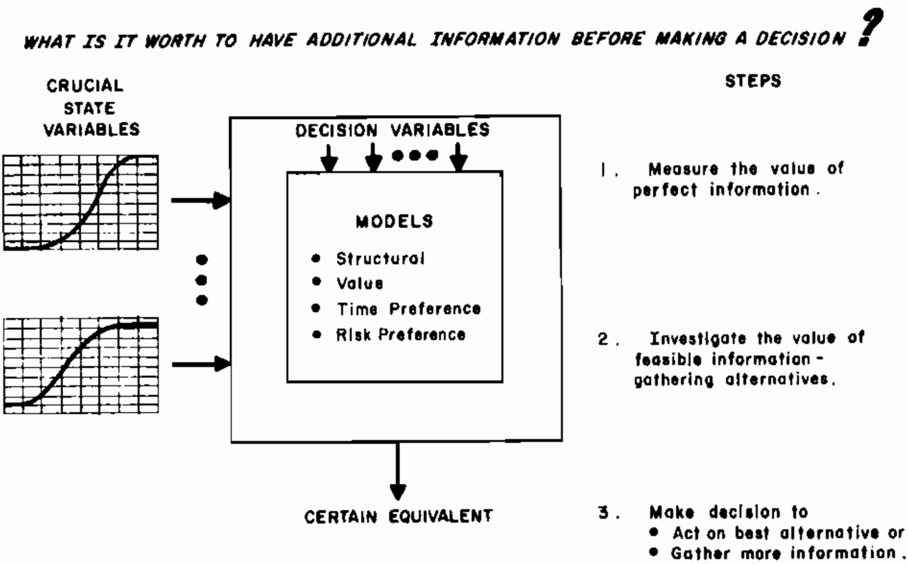

Fig. 5—The Informational Phase of the Decision Analysis Cycle

its real-world cost is a profitable alternative for the decisionmaker.

The third step of the informational phase is to examine the values of the information-gathering alternatives and to select those which, if any, should be pursued before the primary decision is made.

If time permits a profitable information-gathering program to be performed, the program will lead to new probability assignments on the crucial variables, and it may even result in changes to the basic structure of the decision model. When all the changes that have been brought about by the experimental program have been incorporated into the model, the decision analysis cycle is repeated. Finally, the informational phase is performed again to determine whether further information-gathering would be valuable. At some point, further information will cost more than it is worth, and the decision alternative with the highest certain equivalent should be chosen for implementation.

The Organizational Implications of Decision Analysis

The formalism of decision analysis is especially valuable for vertical communication in a management or government hierarchy. For example, the organizational value structure determined by policymakers at the DOD level must be wedded to the detailed information and technical expertise possessed by researchers, operators, and managers. Decision analysis provides an excellent means for accomplishing this union. It provides a structure for the delegation of decisionmaking to lower levels of command and for the synthesis of information from diverse areas for decisionmaking at high levels.

The introduction of decision analysis may cause changes in organizational structure. Special staffs concerned with the performance of decision analysis are already beginning to appear in industry and government. These people should be trained not only in decision analysis, but in probability, statistics, operations research, economics, modeling, and computer implementation, and they must be responsible for ensuring that the highest professional standards of logic and ethics are observed in any decision analysis. We must bury the tendency to say, "I have made my decision; now build me a case to support it."

The special training for decision analysts must be accompanied by special training for decisionmakers. They need to know much more than they now do about logical structure and probability if they are to obtain full advantage from the decision analyst and his tools. Much of this training can be given in special courses to introduce decision analysis to management. For instance, introductory courses could easily be established in the curricula at the Naval Postgraduate School, at the Naval War College, and at the Naval Academy.

BIOGRAPHIC SUMMARY

Lt. N. Clark Williams is in his fourth year of postgraduate study in the Department of Engineering-Economic Systems at Stanford University under the Navy's Junior Line Officer Advanced Educational Program (Burke Program). Following graduation from the U.S. Naval Academy with the Class of 1968 and upon completion of submarine basic training, he was assigned to duty on board the U.S.S. *Tusk* (SS 426). In June 1970 he reported to Stanford University for his present tour of duty. His postgraduate work has included a year of research and professional practice in Decision Analysis with the Decision Analysis Department at Stanford Research Institute, Menlo Park, Calif.

Summary

Decision analysis has many advantages, of which we have discussed just a few, such as its explicit recognition of uncertainty and values, and its ability to place a dollar value on the gathering of additional information. The formal logic of decision analysis subjects the component elements of the decision process to scrutiny, to ensure that judgments and information are applied in a logical and consistent way. The basis for a decision becomes as evident as the decision itself. Information gaps can be uncovered and filled, and differences in expert opinion can be examined openly.

While the decision analysis formalism will not do much for the decisionmaker who has yielded to parochial interests and who is committed to expediency, it can provide the conscientious decisionmaker with a procedure for applying logic in the challenging environment of spiraling weapons costs, lower budgets, shifting national priorities, and unprecedented public scrutiny of the defense acquisition process. It will cost you virtually nothing to find out about decision analysis, so why not take the plunge? Try it; you'll like it!

APPENDIX I

APPLICATORY CASE STUDY

Since its emergence 6 years ago, decision analysis has been applied to a growing list of complex and varied decision problems. It has been used to evaluate new products, define market strategies, analyze facilities expansion, devise a commodity buying strategy, derive the value of information in mineral exploration, and develop financial portfolio management models.

Decision analysis has also been applied to Government problems in the areas of space exploration,[5] nuclear reactor development, weather modification,[6] forest fire suppression, and national energy policy. In brief form, the following example demonstrates some of the concepts introduced in this paper:*

A major chemical company had developed a biodegradable pesticide that could replace a DDT-based pesticide, the company's principal product line. The production costs would run somewhat higher on this product than on the DDT-based one, but the company management hoped that because it would not have the harmful environmental effects of DDT, the public would be willing to pay somewhat more for it. They did not expect this to make up for the higher costs, but they hoped the customer response would be so good that they would gain a large enough share of the market to offset this lower margin.

Then if the Government decided to ban DDT after this company had shown that the product could be manufactured, they would be in an extremely favorable position. In that case, even after their competitors came out with biodegradable pesticides of their own, this company would probably retain a large share of its new market.

The decision, however, was complicated by a number of uncertainties. If, for example, it turned out that the public was not willing to pay a higher price for the product, the company would be forced to withdraw it from the market. Because of the favorable environmental effects of the product, they might be put under public and governmental pressure to keep it on the market even at a loss to themselves.

The company had been studying the problem for nearly 7 years without being able to come to a final decision. It involved a $100 million investment in new production facilities and $50 million in new marketing outlets. The company had built a pilot plant to pinpoint manufacturing costs but had never market tested the product because of the pressures that might be brought to bear on them if it became generally known that such a product could be made.

The president of the company had been advised to abandon the entire project because "the risk was too great." However, the new product line was the pet project of an important stockholder and member of the board. Each time a study team reported negative results, he suggested a new aspect of the problem for study, a phenomenon to which every one of us has been either victim or witness.

The decision analysis team began by interviewing management and the various marketing and engineering experts designated by them. Then they sorted out the variables affecting the decision, defined and related them. Next they conducted a deterministic sensitivity analysis and identified the crucial variables.

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*This example is drawn from "Decision Analysis Helps Managers Decide," an article which appeared in a recent issue of *Investments in Tomorrow*, a periodic publication of Stanford Research Institute, Menlo Park, Calif. Permission to use this material is gratefully acknowledged.

The probability distribution for each of the crucial variables was determined by interviewing the relevant experts. The decision analysts asked such questions as "What is the probability that market size will be greater than X? Less than Y?" (The preceding questions are simplistic examples of interview questions.) Analyzing and plotting the responses, they obtained for each crucial variable a probability distribution curve like the one for market size in figure 6.

The decision analysts then used the structural, value, and time preference models to compute the "profit" lottery curve in figure 7 for the alternative which called for the production and sale of the biodegradable product. (In industrial applications, the measure of worth is often profit, hence we have a profit lottery instead of a worth lottery. Profit here is defined as the discounted value of all revenues minus all costs, including investments.) The curve shows that a maximum profit of $200 million could be realized if all the variables were at their most favorable values—that is, if market size were maximum, costs minimum, prices maximum, et cetera. But since the expected profit is shown to be less than zero, the curve indicates that the product should be dropped.

When the president saw the graph in figure 7, he was delighted. "Just what I've always tried to tell them," he said. "We could win or lose $200 million, and we just don't know what will happen."

But the decision analysts replied, "Wait a minute." And they showed him the graphs in figures 8 and 9 to illustrate the results of their stochastic sensitivity analysis. These profit lotteries were obtained by assigning particular values to one of the crucial variables (manufacturing costs for the figure 8 graphs and market size for the figure 9 graphs) and leaving the remaining variables uncertain as before.

The graphs in figure 8 show that even if costs turned out to be what the experts considered minimum, the expected profit would be less than zero. Thus detailed information on these costs would not change the decision dictated by the general lottery (figure 7). Yet, because the company had the expertise to develop this information, they were in the process of spending more than $750,000 to do so.

This is not an uncommon finding of decision analysts. Far too often decision-makers spend disproportionate sums of money to gain information on variables that are not important to their decisions. It is virtually a truism that people do not get the information that would be valuable to them; they get instead the information that is easy to acquire or the information that they know how to acquire. Decision analysis can help the decisionmaker avoid this pitfall.

Market size, which the company had made little attempt to determine, turned out to be the most important crucial variable. As shown in figure 9, if the market size were in the "very large" range, the expected profit would be large indeed—about $90 million. Under these circumstances the company management would no doubt decide to proceed with the product. However, the analysis showed that there was only a probability of 0.2 that the market would be this large. And if it were smaller than this, the profit outlook would not be nearly so bright, in which case the company would not proceed with the product. Thus it was of paramount importance to the decision to know the market size.

The decision analysis showed that the value of knowing the market size, i.e., the value of perfect information, was 0.2 x $90 million plus 0.8 x $0 million, or $18 million, less, of course, the cost of obtaining the information. The market test itself would cost about $2 million.

In addition, there would be the cost of counteracting the bad publicity resulting from a decision to withdraw the product from the market. The corporate officials estimated that an advertising and promotional campaign that would accomplish this end would cost another $2 million. Since this would be necessary only if the results of the test showed that the market was less than very large, the probability that it would occur was 0.8—the same as the probability that the market would not be very large. Thus the value of the market test, assuming that it would yield perfect information, was $18 million - $2 million - $2 million x 0.8 = $14.4 million.

To summarize: If the company conducted the test, they would have a 20 percent chance of learning that the market was very large. If the market turned out to be very large, the decision would be to continue to full-scale marketing with an expected profit of $90 million less the $2 million cost of the market test. But there was also an 80 percent chance that the market size would be less than very large. In that case they would discontinue the test and withdraw the product from the market at a loss of about $4 million.

The results of the analysis were presented to the corporate officers as a chance to gamble on the spin of a wheel with a 20 percent chance of winning $88 million and an 80 percent chance of losing $4 million.

The vice president of marketing said, "Absolutely not! We never spin unless we have at least a 50-50 chance of winning." But the president was not so sure. "Not even when we can win $88 million and we only stand to lose $4 million?" he asked.

To the vice president of marketing it looked like a very poor bet, for he assumed that he would have to take the blame for a bad outcome. With an 80 percent chance of being a loser, he was highly averse to taking a risk.

The president, who saw the bigger picture, felt that the risk of losing $4 million was justified because of the large potential profit.

The company decided to go ahead with the product although it was a time of great uncertainty in the marketplace. The Government clamped restrictions on DDT sooner than they had expected, and many of the competitors had to follow suit. As a result, this company ended up in a somewhat better position than if they had not made the decision to proceed. This outcome, although not the bonanza the company had hoped for, seems to vindicate the decisionmaker for having made the decision. Recall, however, that there is a difference between good decisions and good outcomes.

Although this decision involved civilian managers and a profit-oriented corporation, the Navy has myriad decisions that could be served equally well by decision analysis.

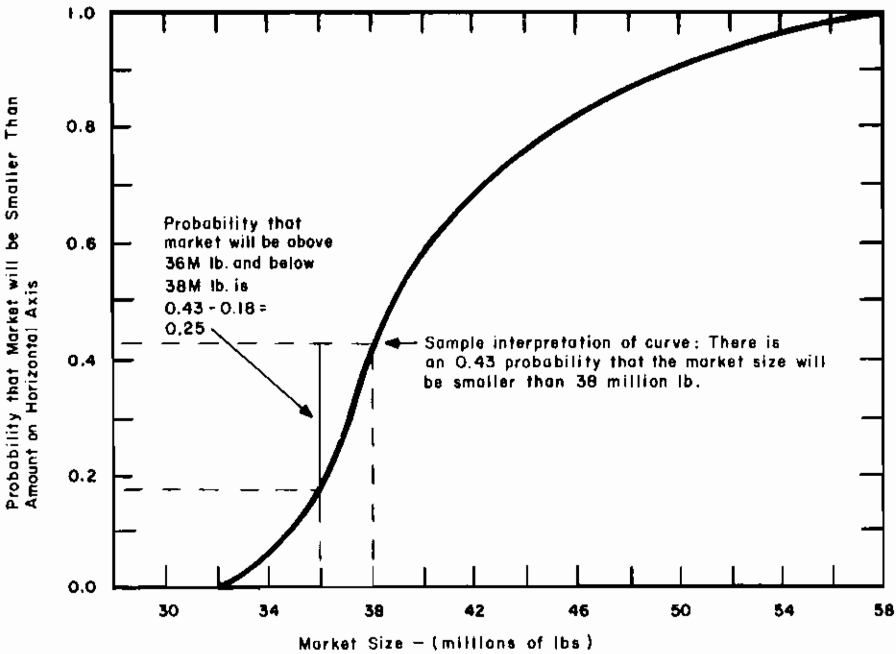

Fig. 6—Uncertainty in Market Size

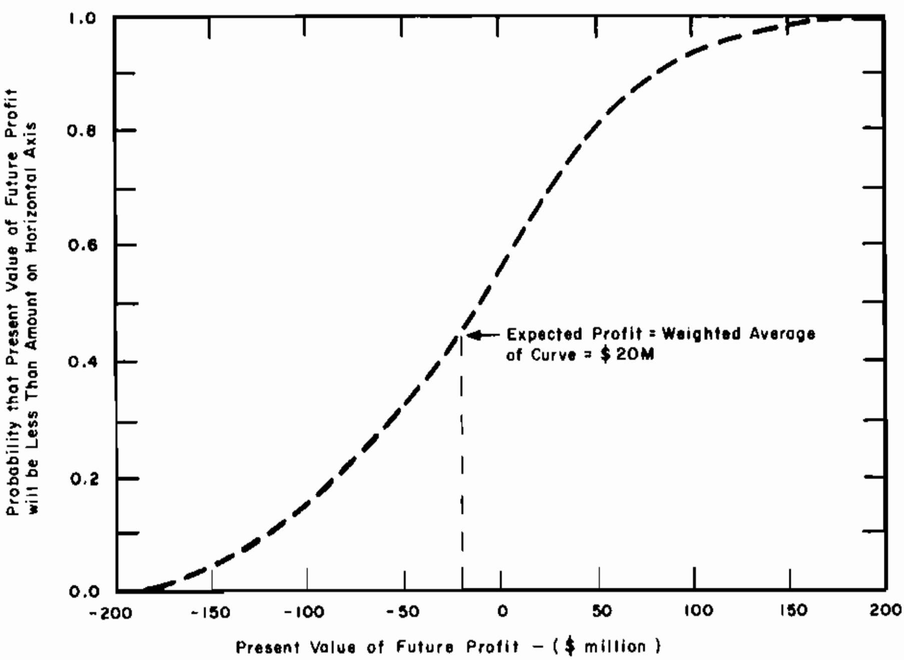

Fig. 7—Profit Lottery

Source: "Decision Analysis Helps Managers Decide," *Investments in Tomorrow* (Menlo Park, Calif.: Stanford Research Institute).

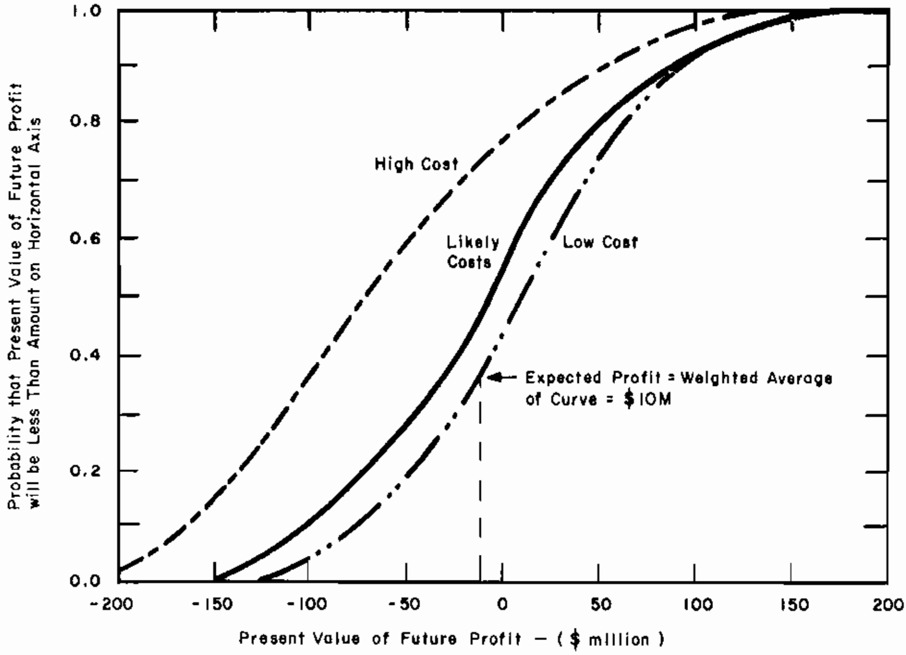

Fig 8—Effect of Manufacturing Costs on Profit Lottery

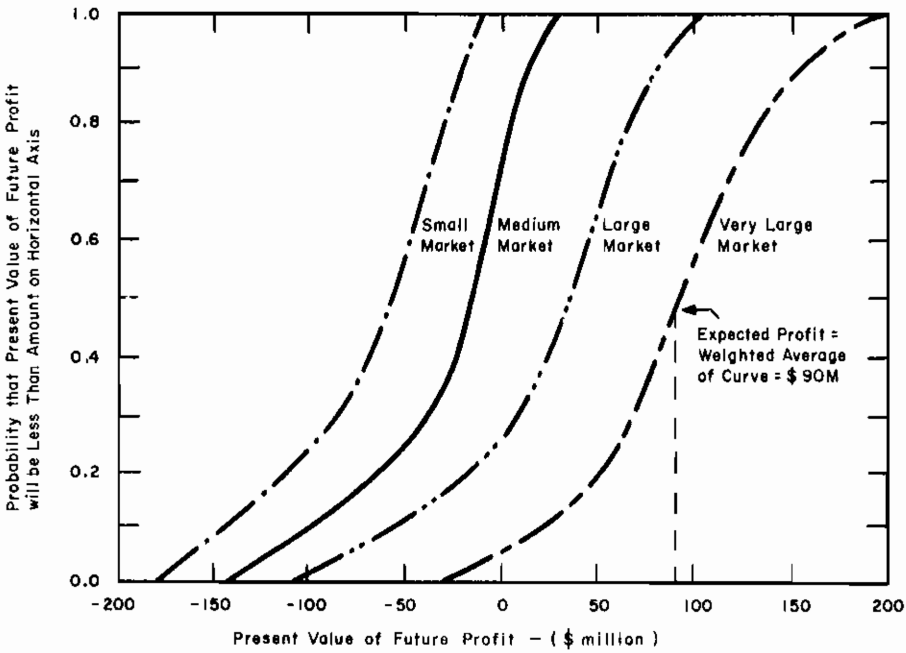

Fig. 9—Effect of Market Size on Profit Lottery

Source: "Decision Analysis Helps Managers Decide," *Investments in Tomorrow* (Menlo Park, Calif.: Stanford Research Institute).

NOTES

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The rarest gift that God bestows on man is the capacity for decision.

Dean Acheson: Speech at Freedom House, New York City, 13 April 1965