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Handbook of Systems Analysis: Volume 1. Overview. Chapter 8. Guidance for Decision

Schwarz, B., Bowen, K.C., Kiss, I. and Quade, E.S.

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HANDBOOK OF SYSTEMS ANALYSIS

VOLUME 1. OVERVIEW

CHAPTER 8. GUIDANCE FOR DECISION

B. Schwarz, K. C. Bowen, Istvàn Kiss,
and Edward S. Quade

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INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS
A-2361 Laxenburg, Austria

FOREWORD

The International Institute for Applied Systems Analysis is preparing a Handbook of Systems Analysis, which will appear in three volumes:

- Volume 1: Overview is aimed at a widely varied audience of producers and users of systems analysis studies.

- Volume 2: Methods is aimed at systems analysts and other members of systems analysis teams who need basic knowledge of methods in which they are not expert; this volume contains introductory overviews of such methods.

- Volume 3: Cases contains descriptions of actual systems analyses that illustrate the diversity of the contexts and methods of systems analysis.

Drafts of the material for Volume 1 are being widely circulated for comment and suggested improvement. This Working Paper is the current draft of Chapter 8. Correspondence is invited.

Volume 1 will consist of the following ten chapters:

1. The context, nature, and use of systems analysis
2. The genesis of applied systems analysis
3. Examples of applied systems analysis
4. The methods of applied systems analysis: An introduction and overview
5. Formulating problems for systems analysis
6. Objectives, constraints, and alternatives
7. Predicting the consequences: Models and modeling
8. Guidance for decision
9. Implementation
10. The practice of applied systems analysis

To these ten chapters will be added a glossary of systems analysis terms and a bibliography of basic works in the field.

Hugh J. Miser
IIASA
A-2361 Laxenburg
Austria

12 October 1981

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CHAPTER 8. GUIDANCE FOR DECISION

B. Schwarz, K. C. Bowen, Istvàn Kiss and Edward S. Quade

1. INTRODUCTION

Previous chapters have presented a simplified description of the systems analysis approach (Chapter 4), and then treated in more detail formulating the problem (Chapter 5), identifying objectives and constraints and designing and improving alternatives (Chapter 6), and, finally, model building and using models to predict the consequences ensuing from each alternative (Chapter 7). This chapter deals with the guidance an analyst can provide, based on the information he has produced regarding the advantages and disadvantages of the various alternatives, to those responsible for selecting an action. This selection can sometimes be uncomplicated, but more often, when there are competing objectives, multiple decisionmakers, or great uncertainty about future conditions, it becomes a complex social process in which conflicts tend to be resolved by bargaining, and political pressures may overpower research findings. The way the results are presented and the information and evidence presented with them can both facilitate and improve the choice.

An analyst can almost never, based on his analysis alone, tell the decisionmaker with confidence: "This alternative should be selected." His mathematical model may designate an optimum action, but it is an optimum only in the domain of the model, for even the most perfect of models corresponds only imperfectly to the real world. Optimization is a technical concept, inapplicable in situations where differing values, uncertainty, ambiguity, multidimensionality, and qualitative judgment are present and possibly dominant. Even with perfect information, the most that can be done is to find the alternative that best satisfies a certain criterion under a given set of assumptions. This is far from full optimization, which would require considering simultaneously the complete set of consequences for every choice of alternative, taking into account the full range of future events and their associated probabilities.

For multiple decisionmakers, there can, in fact, be no optimality; any such concept depends on a particular decisionmaker's values, purposes, abilities, and needs. Consequently, as Boothroyd (1978) puts it, "...would-be-scientific intervention is at best a way of getting things righter, not of getting them right." Earlier, citing other reasons, Charles Hitch (1960b) had laid the ghost of optimization to rest in his retiring address as President of the Operations Research Society of America: "...Most of our relations are so unpredictable that we do well to get the right sign and order of magnitude of first differentials. In most of our attempted optimizations we are kidding our customers or ourselves or both. If we can show our customer how to make a better decision than he would otherwise have made, we are doing well, and all that can reasonably be expected of us."

Thus, in systems analysis, whenever the terms optimum, optimal, and optimization are found, they must be interpreted with great caution, for they refer to something that is, at best, a suboptimization.

The goal of the analyst may, in fact, be to do better than to produce, by cost-benefit or other criteria selected by the decisionmaker, the correct ranking of the limited set of alternatives he has examined so that a "best" can be selected from among them. To this end he must, of necessity, learn a great deal about the subject of inquiry; but nevertheless he may remain far from having the expertise of the client and his staff. Thus, he may instead, as Goeller (1972, 1977, and section 3.4) and Holling and his colleagues (1978) do, as discussed in section 8.8, seek a presentation that will enable the decisionmaker to understand the strengths and weaknesses of—and the tradeoffs among—the various alternatives, so that a new and better alternative can be generated before action is taken.

2. CRITERIA

A criterion is a rule or standard by which the analyst can rank alternatives for the decisionmaker. The alternative ranked first indicates the alternative among those ranked that is best or is most consistent with the decisionmaker's objectives according to this standard.

As an example, suppose a decisionmaker's objective were to provide electric power for his constituents by building a dam on a certain stretch of river. Assume he has a budget of 200 million dollars available for the project. A criterion for ranking the various dams that might be built in different designs and locations along the river could be to rank the ones that can be constructed for the available budget in decreasing order of power output. Although the purpose of a criterion is distinct from that of an objective, the decisionmaker could state his objective in exactly the same words, namely, to build the dam with the greatest power output that can be constructed within the available budget. Because statements of objectives are frequently made in this way, the terms criteria and objectives are often used interchangeably.

To maximize a benefit such as power output from a project subject to a cost constraint (as above) or its equivalent, or to maximize the cost subject to a benefit constraint, is a commonly used criterion. It works well when the significant costs are monetary and there is a single dominant benefit. It is also used when the benefits are difficult to measure in monetary terms, say something like crime reduction or esthetic satisfaction. This orientation is called the cost-effectiveness criterion. Again it may be stated as an objective, for the decisionmaker may say he wants to select the most cost-effective alternative.

For public decisions, say for the choice of an airport location, a common criterion is that of cost-benefit analysis, that is, one chooses the location for which the net benefits exceed the net costs by the largest amount. A benefit may be interpreted as something that brings about a Paréto improvement—a change that makes at least one member of the community better off and none worse off. A cost does the opposite. The measurement problems associated with cost-benefit analysis are enormous and are discussed later in section 8.5; for an explanation of the underlying principles of cost-benefit analysis, see Sugden and Williams (1978).

Many other schemes have been used to combine various indicators into a single index, particularly when the impacts or conseqences are ones whose measurements indicate the worths of the alternatives. One type of index much used in the past is a quotient with the product of the measurements of impacts for which an increase is desirable in the numerator and with the products of the measurements of impacts for which a decrease is desirable in the denominator. Thus, to compare alternative aircraft designs, if the significant indicators are V = speed, R = reliability, C = cost, P = payload, and F = fuel consumption, the index might be VRP/CF. To take account of the differing importance of the factors, exponents might be used.

A far better form of index, if a single index of worth is to be used, is one developed by utility analysis. This form of analysis permits the decisionmaker (or a group of decisionmakers) to determine both the "utility" or "satisfaction" that is associated with different values of an impact and the tradeoffs between the values of different impacts. The theory offers a theoretically sound way, through formal questioning, for an analyst to help the decisionmaker to develop an index (Raiffa 1968; Keeney and Raiffa 1976).

Criteria are tied to objectives; the criterion the analyst would like to use is the one that ranks the alternatives in order of consistency with the decisionmaker's objectives. The decisionmaker may, and probably does, have objectives that he does not reveal to the analyst, possibly because he doesn't realize he has them until he is forced to make his decision. Hence, for this reason and because the analysis itself is always imperfect in one way or another, the analyst should regard his rankings as guidance rather than a rule for choice. He may want to present rankings according to several criteria; to say to his client "If you regard X of overriding importance, then C is indicated; but if, as many people do, you regard Y of essentially equal importance, then B may be your choice."

3. SATISFICING

Since true optimization is impossible, satisficing, or replacing objectives by constraints, moves closer to the world as it actually is. The reasons, as summarized by Simon (1969, p. 64), who supplied the name, are: "In the real world we usually do not have a choice between satisfactory and optimal solutions, for we only rarely have a method of finding the optimum. ...We cannot, within practicable computational limits, generate all the admissible alternatives and compare their relative merits. Nor can we recognize the best alternative, even if we are fortunate enough to generate it early, until we have seen all of them. We satisfice by looking for alternatives in such a way that we can generally find an acceptable one after only moderate search."

To satisfice, lower bounds are set for the various goals that, if attained, are "good enough." An alternative is sought that will at least exceed these bounds. A unique solution is not sought and conflicts between goals do not have to be resolved. The satisficer does have to worry that the performance standards are not set too high, for then it may be impossible to satisfy the constraints. An alternative is usually considered to be good enough if it promises to do better than has been done previously.

Satisficing is, in fact, far more common than the use of the term would indicate. Once a satisficing solution has been obtained, it may be possible to improve it. The applied systems analyst normally works under sharp time restrictions. He may have just enough time to produce a solution that is "good enough" for the momentary situation, i.e., better than what is currently being done— and this may be all that the decisionmaker really needs.

4. SUBOPTIMIZATION

The choice of criteria and objectives is made more difficult than otherwise when a decisionmaker, as he often must, undertakes to contribute (he hopes!) to the solution of a broad problem by finding a better way to handle the one aspect with which he is particularly concerned. Authority is everywhere divided; all decisions cannot be made at the highest level, even when the authority to do so exists. Thus, many problems are subproblems, parts of problems that for an "optimum" solution should be considered in the "big picture," but the decisionmaker does not have the time or the authority to do more than to see to the improvement of his sector. Analysts, like decisionmakers, for these reasons as well as being forced by the difficulties of solving their problems, must frequently devote their attention to actions that pertain to only part of the problem. In the language of systems analysis, they "suboptimize."

These attempts are suboptimizations because it is almost always possible to do better if all of the factors that could influence a solution can be considered simultaneously and the decisionmaker were able to make his selection from a larger net of alternatives.

There are reasons to reject suboptimization, but as Hitch (1960a) comments:

> It might appear then that it would make sense to *begin* with some broad "given" or accepted objectives; to derive from them appropriate local or sub-objectives for the systems problem in hand; and then to design the analysis to maximize, in some sense, the proximate objectives...
>
> Not only is this a plausible approach; it is in some special cases an acceptable one; it is usually (not always) better than making no systems study at all; and it is frequently, given limitations on available

time or manpower, the only feasible approach. I think I was the first to use the term "sub-optimization" to describe this style of operations research (in 1952), and I am no implacable or dogmatic foe of its use. Some of the most rewarding systems studies have in fact been low level sub-optimizations. [Italics in the original.]

But as Hitch goes on to say, a suboptimization may not be satisfactory unless the criteria for the lower-level problem are consistent with those for the higher-level problem. Thus, to avoid inconsistencies, the analyst must give careful thought to the criteria and objectives for the full problem before deciding on the ones that should be used in the subproblem. An illustration may help (Quade 1975):

> For example, in the design of a car-parking operation for an amusement park, one size of lot and pricing system might be derived from a suboptimization in which the criterion is that of maximizing net revenues from parking and another size lot and pricing policy from an analysis that sought to maximize net revenues from the amusement park as a whole. Lack of parking for a few people, who then go elsewhere, might lead to considerable saving in land costs for parking and in salary for attendants, and thus in revenues for the lot, but the loss in goodwill, and thus in revenues for the park as a whole, might be serious.
>
> A policy more consistent with the higher-level objective, and thus a better policy for the lot, might simply be to provide parking for all customers—or even to provide it free. We cannot know *a priori*, however, that income from a parking lot should be small relative to the income for the facility it serves. Whenever there is little opportunity for visiting the facility except by private car, a significant general admission might be more acceptable if disguised as a parking fee.

The advantage of suboptimization is that more detail can be taken into account in the narrower analysis. Models, because they involve fewer factors, may yield more accurate predictions. But the need for consistency between criteria for the full problem and those of the partial problem poses difficulties in selection.

5. COST-BENEFIT ANALYSIS AND THE COST-BENEFIT CRITERION

Decisionmaking is often described as a weighing of benefits against costs if the benefits and costs are interpreted in the broad sense of referring to *all* kinds of advantages and disadvantages of different decision alternatives. Sometimes risk is considered as a cost, sometimes as a separate dimension; however, it is a cost, since we are willing to pay to avoid it. Comparisons of various alternatives in terms of benefit-cost-risk can therefore be considered a general framework of analysis (Dror 1975). Nevertheless, when the term cost-benefit analysis is used, it usually refers to a somewhat simplified type of analysis, well known to economists, and having its origin in welfare economics.

In economic cost-benefit analysis the analyst identifies the different types of consequences of each alternative, usually a governmental project (e.g., the location of an airport or a power station). The consequences are estimated quantitatively and the quantities converted to monetary units. Monetary benefits and costs are then summed separately with proper attention to probability and time of occurrence. The *cost- benefit criterion* means a ranking of the alternatives in decreasing order of the excess of benefits over costs. It should be borne in mind that not all costs and benefits, even though expressed in the same monetary units, can necessarily be added in a straightforward way, without additional scaling: costs like benefits have to be treated initially as a multidimensional variable.

Cost-benefit analysis has several attractive characteristics. The cost-benefit criterion seems relevant for decisionmaking and defines an unequivocal method for ranking alternatives. Also, theoretically, it can be used to guide choice between such diverse alternatives as allocating funds for a water project (with irrigation, electric power, flood control, and recreation as goals) or for a health program to reduce infant mortality. If the projects are roughly of the same scale, one prefers the project with the greater excess of benefits over costs; if the projected benefits are less than the costs, then the project should not be undertaken.

Ideally, in an application, all consequences associated with implementing an alternative for all future time should be identified, and then the probabilities of their occurrence and their benefit or cost to society determined. The expected loss or gain to society is calculated by multiplying each amount by the probability of occurrence. A discount rate is then assumed and the time streams of costs and benefits are discounted and summed to obtain their present values. The totality of benefits minus the totality of costs is then used to rank the alternatives. The translation of consequences of implementation into monetary terms includes estimates by the analyst of the prices that would have been attached to various goods and services if a perfectly competitive market had existed. In principle, cost-benefit analysis can thus associate with each possible choice all the inputs and outputs, all the positive and negative effects, including spillovers, with their probabilities and times of occurrence, condensing everything into a single number. However, a number of complications arise in connection with practical applications.

In practice, to quantify all types of effects and translate them into monetary terms may be very difficult and any method used will be open to question. For instance, pollution effects can often not be considered as quite equivalent to some sum of money. Different decisionmakers may also have different time preferences, and these may not be conveniently expressed through the discount rate. Further, a general assumption behind the cost-benefit approach is that undesirable distributional effects can be corrected by transfer payments; costs and benefits, however, often accrue to different categories of people and satisfactory compensation to those who lose can often not be found.

As a consequence of the complications mentioned above there are numerous objections to the use of a cost-benefit criterion. One is that it is easily subject to abuse, since so many critical assumptions tend to be buried in the computation. The choice of a discount rate is particularly tricky. For instance, to promote a project with high installation costs but with the benefits deferred in time, advocates would argue for a low discount rate (two percent has been used for some water projects where the benefits were marginal and a long time in the future). Perhaps the most fundamental objection to the cost-benefit criterion is that it requires the analyst to make judgments (for instance in connection with distributional effects) which in fact are value judgments of the sort that should be left to the responsible decisionmaking body.

Again, in theory, a considerable advantage of the cost-benefit criterion is that it permits comparisons of very different projects. But experience in applications indicates that it is more likely to be used successfully when the decision alternatives are rather similar, i.e., with consequences similar in type and involving the same scale of effort.

To give an illustration of the possibilities and limitations of cost-benefit analysis, we will use a hypothetical application. Assume that an additional airport is considered to be required in a city area because of increasing air traffic. As the existing one cannot be extended, the problem is to find a suitable location for a second airport. To simplify, we assume further that there are several suitable and uninhabited land areas and that air traffic does not cause any negative side effects, i.e., there are no noise or air pollution problems. To calculate the costs and benefits of the different locations, the analyst has to estimate the impact on future air and surface travel, the monetary worth of savings in travel time, etc. These estimates may involve considerable uncertainties, but rough approximations are likely to be obtainable. Because of the uncertainties, it may not be possible to arrive at a definite ranking order. Nevertheless, very bad alternatives can probably be revealed as such, and the analysis can help the decisionmakers to focus their further attention on a subset of the original alternatives, a subset that is likely to contain only reasonably good alternatives.

To make our hypothesized airport example somewhat more realistic, let us now assume that the alternative airport locations will, to a varying extent, bring noise disturbances into residential areas and also require that some residents, factories, etc. be displaced. This means that there will be a group of people who probably cannot be compensated in a way they find quite satisfactory. Surely this information is important to the decisionmakers and should be brought to their attention; the cost-benefit criterion alone, in this case, is not the most suitable basis for ranking the alternatives and needs to be supplemented in some way, say by a "scorecard" presentation, as described later.

The term cost-benefit analysis is also used to describe studies whose results are not quite as condensed as a strict cost-benefit criterion requires. In such cost-benefit analysis, it is usually recommended that benefits and costs that cannot be expressed in monetary units in a satisfactory way be displayed separately. When there are such effects more complex information has thus to be communicated from the analyst to the decisionmakers. For the analyst to choose when and how to do this, the information exchange between the analyst and the decisionmakers is of considerable importance. The analyst needs information about the decisionmaking situation and about what the decisionmakers consider important, and he has to structure the communication of his results in a way to fit the prevailing decision situation and in the language of the decisionmaker.

In evaluating risky projects with highly adverse but rare consequences and negligible costs, a risk-benefit rather than a cost-benefit analysis is frequently used (Jennergren and Keeney 1979, Fischhoff 1977). The fundamental idea is to appraise whether or not the benefits outweigh the risks. It is used, for example, in deciding whether various food additives and drugs should be barred from the public.

6. COST-EFFECTIVENESS ANALYSIS

If we now turn back to our simplified airport example, it may happen that the study is being carried out at a time when the decision to build a second airport has already been taken. Perhaps several feasible and quite attractive alternative locations have been found and general estimates or judgments have indicated that the benefits of a second airport will exceed the costs. In this case it may be an unnecessary complication to try to estimate the benefits in monetary terms, for some *measure of effectiveness* (e.g., some kind of air-travel capacity measure) may be of more interest. More generally, a project is usually undertaken to achieve some objective; the measure of effectiveness should indicate the extent to which the objective is achieved.

This leads us to a type of criterion of choice which can be termed cost-effectiveness. In this, alternatives are ranked either in terms of decreasing effectiveness for equal cost or in terms of increasing cost for equal effectiveness. Sometimes the maximum of the ratio of effectiveness to cost is used to indicate the preferred choice, but this is open to all the objections that apply to the use of ratios for criteria (Hitch and McKean 1960) and will require additional information to fix the scale of the effort, as seen in Figure 6.1. Here, typical cost-effectiveness behavior is illustrated for two programs. Whether 1 is preferred to 2 depends on the scale of the effort; if, for instance, the effectiveness must be at least E_2, then 2 must be preferred (Attaway 1968). If, however, the cost cannot exceed C_1, 1 is preferred.

Cost-effectiveness is probably the most commonly used criterion for ranking alternatives. The reason is clear; it provides a comparison in terms of two factors of crucial importance to every decisionmaker–how much he will need to spend, and to what extent the action he takes will get him what he wants. It may be a sufficient basis for choice only in those rare instances when "other considerations" are not significant, but the information it provides is always helpful.

The cost-effectiveness criterion is open to a number of objections. One is that cost as used in cost-effectiveness reflects only the costs that are inputs—

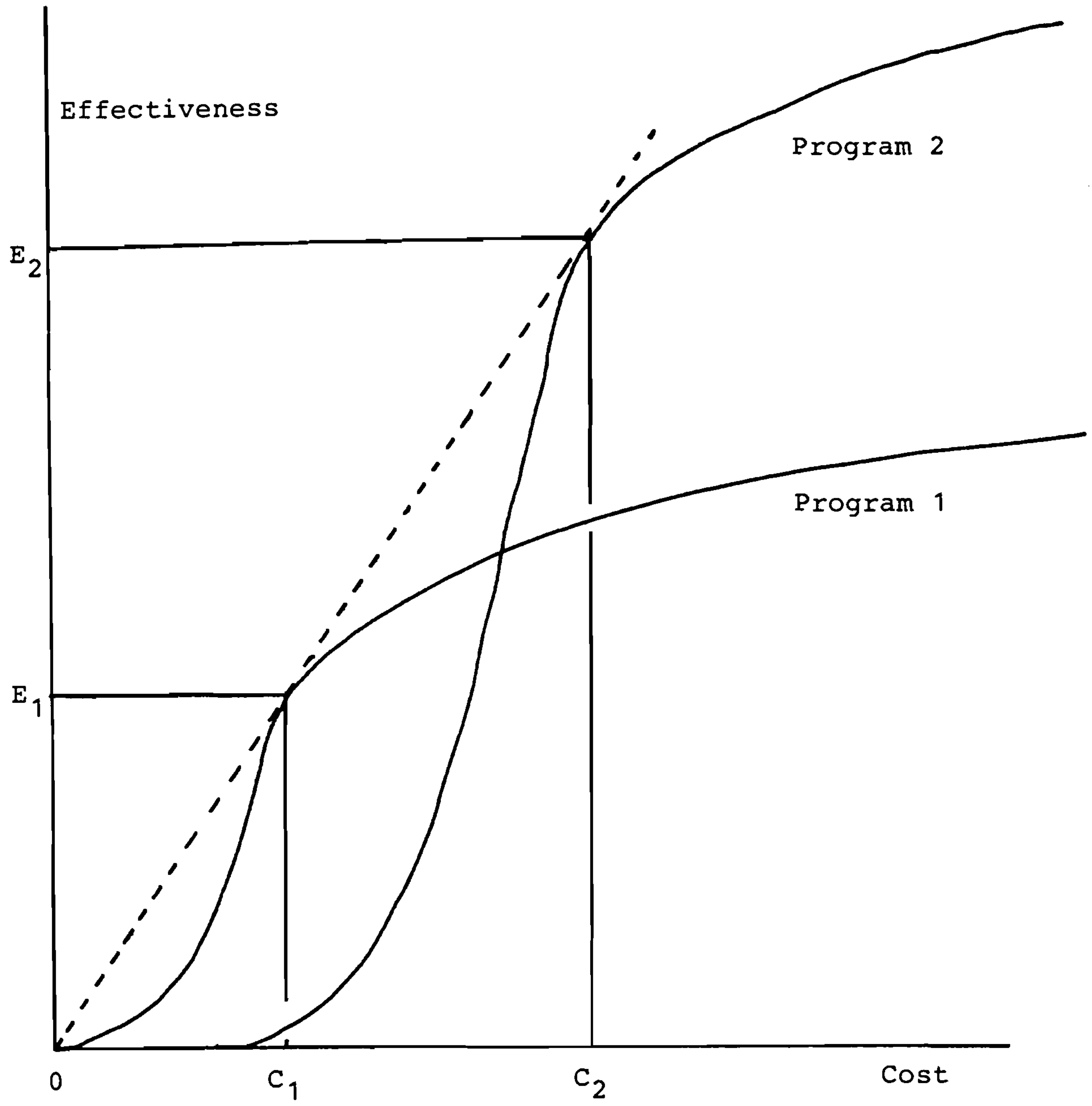

Figure 8.1. Typical cost-effectiveness curves for two projects achieving the same maximum cost-effectiveness ratio. The dotted line is a line of constant cost-effectiveness, and the common maximum occurs where the curves are tangent to this line.

the money, resources, time, and manpower required to implement and maintain an alternative. The penalties or losses that may accompany an implemented alternative—it may, for instance, interfere with something else that is wanted or bring undesirable consequences to other people—are costs that are not taken into account.

Ordinarily, effectiveness does not measure value, but is merely a proxy for some aspect of it. A different choice of how we measure effectiveness can lead to a different preference among alternatives. For example, if the objective is to increase traffic safety and we choose as our measure of effectiveness the decrease in fatalities, we may then give high priority to reducing accidents where two cars collide at high speed, for these are very serious. But if our measure is the decrease in the economic cost of accidents, then priority may go to the avoidance of low-speed collisions in rush-hour traffic, for these are very numerous.

Another defect is that the people who must pay the costs of a decision and those who stand to gain may not be the same. Unless the alternatives are so similar that this aspect can be neglected, a decision based on a cost-effectiveness criterion may mean trouble for the decisionmaker. Again, there is a likely clash of values.

Finally, even if cost and effectiveness were fully and properly determined, the decisionmaker would still be faced with the problem of what to choose. He needs some way to set the scale of effort—either the cost he must not exceed or the effectiveness level he needs to achieve. Sometimes this can be provided by setting the maximum cost so that it corresponds to the "knee" of the cost-effectiveness curve (Figure 8.1), since very little additional effectiveness is gained by further investment.

It is clear that the type of cost-effectiveness criterion we have discussed here is often inadequate for decisionmaking problems for which multiple objectives, spillover effects, or the distributional aspects are important characteristics.

7. DECISION ANALYSIS

Cost-benefit analysis, as presented above, can be considered as a means of reconciling competing objectives through converting the various consequences into monetary units. The analysis is merely done for a higher-level objective—to find the course of action that brings the greatest excess of benefits over costs. As the benefits and costs associated with any proposal are quantified in monetary units, a system of weighting the various consequences of courses of action is, in effect, being used.

Numerous other schemes for using a weighted combination of the consequences to provide a preference ranking of the alternatives have been tried. Some of these work satisfactorily when the decisions involved are of a repetitive type. Under the name of decision analysis a considerable body of knowledge has been developed which, in principle, is applicable both to one-time decisions and repetitive decisions.

In the decision analysis approach, the analyst models the value system or preference structure of the decisionmakers so as to be able to predict with the model what the decisions would be, were the decisionmakers to be presented with the full set of alternatives and their consequences. To do this, the analyst constructs a function of the form $V=f(x_1,x_2,\ldots,x_n)$ representing the decisionmaker's value or utility rating of each alternative. Here the x_i's, $i=1,2,\cdots n$, are measures (on appropriate scales) of the consequences, properties, aspects, or anything else associated with an alternative that the decisionmaker would take into account in estimating the value of the alternative.[1] Thus, if competing designs for communication satellites were being ranked, x_1 might be the initial investment cost, x_2 the expected mean time to failure, x_3 the number of channels, and so on. The total number of factors that the decisionmaker considers is n.

[1]For a more detailed description of the paradigms of decision analysis, see chapter 1 in Keeney and Raiffa (1976).

Any aggregate approach of this type, like the cost-benefit approach, has two serious disadvantages. One is that a great deal of information is lost by aggregation; the fact that alternative A has environmental problems whereas alternative B has political implementation problems is suppressed. The second is that any single measure of value depends on the relative weights assigned by the analyst and the assumptions he used to get them into commensurable units.

To produce anything resembling a valid value function is clearly difficult, and may be impossible in many situations. There are problems both with getting the preference information from the decisionmakers and with putting it together in a usable expression.[2] The first can require a substantial effort on the part of the decisionmakers.

Many analysts believe that, while such value functions are clearly useful for preliminary screening of alternatives, the final designation of a preferred alternative must be made by other means. Particularly when the decision concerns the public sector, and the preferences depend on basic values, the decision thus being essentially a political decision, more disaggregated information needs to be communicated to the decisionmakers. Nevertheless, the analyst may, in the process of developing and using value functions, for his own initial inquiry, find that his understanding of the complexity of the problem, and consequently the advice that he finally offers, has been enhanced.

8. AVOIDING THE CRITERION PROBLEM

If someone is to help me decide whether something I think I would like to have is worth what I would have to give up to get it, the most informative way for him to do so is to present me with a full and honest description of what I would be getting, and getting into, including all negative aspects and side effects. I would judge this preferable to being told that, because of previous decisions or statements, if I am to be consistent, I should do so and so. Many decisionmakers, ranging from individuals to the body politic, have this same feeling.

[2]For examination of the basic assumptions behind decision analysis and the consequential prob-

The obvious way of presenting such information is by means of a two-dimensional array or matrix. Until recently Bruce Goeller has been almost alone in advocating the use of such an array as the replacement for ranking the alternatives by cost-benefit or other criteria in presenting the results of a systems study to policymakers. On a scorecard, as Goeller (1972) calls such an array, the consequences that ensue from a possible decision to select each of the alternatives–the costs, benefits, spillovers, risks, segments of society affected, and in fact, anything about an alternative that the analyst thinks the decisionmaker might want to consider in his decision, including its characteristics and origins if that seems pertinent–are displayed (in terms of the natural units commonly used to characterize them) in a matrix, or tabular array. In such an array, the entries in each column represent the consequences associated with a particular alternative and the entries in a row show how a particular consequence or other characteristic varies from alternative to alternative. [For examples in addition to the displays in Chapter 3, see Goeller 1977.] Improvement by Goeller over the usual presentation lies in the careful selection of units for characterizing impacts, in grouping similar impacts into categories, and in using underlining, shading, or colors to show a crude ranking of alternatives (based on the analyst's interpretation of the decisionmaker's values, of course). The aim is to provide the decisionmaker with an effective "gestalt" of the relative advantages and disadvantages of particular alternatives.

Consider noise impacts as an example. These have usually been reported in terms of land area exposed to a noise level above some specified threshold. But the decisionmaker is more interested in how noise affects people and in how many people. A scorecard can report the number of people exposed to various noise levels on a noise-annoyance scale.

To illustrate the detail with which impacts can be presented, consider the group of "community impacts" reported in a transportation study (Goeller 1972). These report changes in the activity patterns, tax base, and environment

lems in applications, see Tribe (1972) and White and Bowen (1975).

that would occur to the various communities in the region as the result of construction and operation of various alternative transportation systems. Specific impacts displayed in that study include the number of households annoyed by excessive noise, the amount of air pollution, the savings in petroleum consumption, the households displaced by system construction, the amount of land taken, the resulting tax losses to the community, and even such an intangible as the loss of a community landmark.

For oral presentation, color, in the form of transparent colored rectangles placed over the numerical values, can be used to give a quick indication of each alternative's ranking on a particular impact. Goeller used green to show the best value and red to show the worst, with two colors for intermediate values, blue for next best and orange for the next to worst. The numerical values themselves were visible through the colors. Sensitivities to changes in parameters or to different forecasts for the environment were shown by further transparent overlays and the use of multi-colored rectangles.

The scorecard seems to be such a simple and obvious device that no argument for its use is needed. It is extremely flexible. A decisionmaker can see where an alternative he favors is deficient; he can ask what modifications would eliminate the unfavorable impacts from an otherwise promising alternative and whether this action might turn some presently acceptable impact into an unacceptable one. He can call for further analysis to show how changes in the assumptions originally made by the analyst will affect the results. Since the decisionmaker assigns his own weights to the different impacts, the scorecard can help him understand the tradeoffs implied by the decision he is to make. If he chooses A over B he may be trading off substantial increases in noise and future costs for savings in air pollution and initial investment costs. Such tradeoffs are implicit in every decision, but the decisionmaker who views an aggregate index may not see them, for they have been obscured by the process that combined the different impacts into a single measure, even though he may have played a part in agreeing to this process. The scorecard explicitly confronts the decisionmaker with the tradeoffs he must make. To decide, he must weight them subjectively, bringing to bear not only factual knowledge but his feeling for societal values.

A scorecard presentation can also be understood, and used, by the public. Different groups can, in the same way as the ultimate decisionmakers, ask "what if" questions, apply their own weights, and confront the decisionmakers with their views based on much more information than if they had merely an index to go on.

The advantages of the scorecard over an aggregated index for providing guidance to decisionmakers may be summarized as follows:

The scorecard

- seeks convergence to a decision—not agreement on value judgments from the decisionmaker or decisionmakers;
- is understandable and usable by decisionmakers and other groups involved, including the public at large;
- enables impacts and alternatives to be evaluated with minimal interposition of the analysts' biases and values;
- gives attention to qualitative as well as quantitative impacts;
- retains multidimensionality, showing tradeoffs explicitly;
- uses natural physical and thus understandable units.

A disadvantage, for there is one, is that it may present too much information for a decisionmaker to absorb. But this can be handled by careful selection of what to present, holding other information for later presentation when requested, bearing in mind that this process must be kept as free from the analyst's values as possible.[3]

In their adaptive approach to environmental management, Holling and his colleagues rejected cost-benefit and similar criteria to use a scorecard

[3]It has been suggested that scorecards can be considered as a well linked transition from nearly quantitative methods to lexicographic ones. For a possible theoretical basis for this, see Roy (1977).

approach, noting that "...the process of policy comparison through direct reference to the individual indicators is the least ambiguous evaluation technique available. What it lacks in refinement is more than compensated for by the clear communication of relevant information" (Holling 1978, p. 110).

For example, in their study of the interactions of a forest system with a pest called the budworm, they considered 17 impacts (that they called "indicators") grouped into three categories, as shown in Table 8.1. "Extensive experimentation with the system model and interviews with relevant decisionmakers identified five of the indicators listed . . . as primary;" they were (1) the forest volume, measured in cubic meters per hectare, (2) the harvest cost, measured in dollars per cubic meter, (3) unemployment, measured as a proportion of those normally employed in the forest-products industry, (4) recreational quality, measured by an index lying between zero and one, and (5) insecticide applications, measured by a proportion of a standard effort. However, we are interested, not only in values of these indicators, but also their history; therefore, the scorecard technique for this case requires displays of graphs of the indicator values over time, as shown in Figures 8.2-8.5. Holling (1978, pp. 110-112) summarizes the background of these figures as follows:

> . . . The values assumed by these indicators in a simulation of the management policy historically used in New Brunswick are given in Figure [8.2]. In an attempt to improve this policy, new spray and harvest rules were developed and then tested on the simulation. . . The results, presented in Figure [8.3], show improvement in some indicators, notably total forest volume, profits to the logging industry, and recreation, but a somewhat worse situation with regard to employment and insecticide spraying. . .
>
> A modification of the alternative policy was next designed, explicitly tailored to decrease spraying by cutting down trees threatened by budworm. The results in Figure [8.4] show that spraying is indeed reduced, but at a cost of even more irregular employment due to the

Table 8.1. Examples of indicators of known interest taken from the forest-pest (budworm) case study. Source: Holling (1978, p. 109).

Socioeconomic Indicators
Profits to the logging industry
Profits as a proportion of total sales
Cost per unit volume of harvested wood
Cost of insecticide spraying
Unemployment rate reflected by the proportion of mill capacity utilized
Resource Indicators
Volume of wood in trees older than 20 years
Volume of wood in trees older than 50 years
Volume of wood harvested
Proportion of total volume harvested
Volume of wood killed by budworm
Mill capacity
Total forest volume
Environmental Indicators
Visible damage due to budworm defoliation
Damage due to logging operations
Age class diversity of the forest
Number of high quality recreational areas
Insecticide impact in terms of fraction of province sprayed

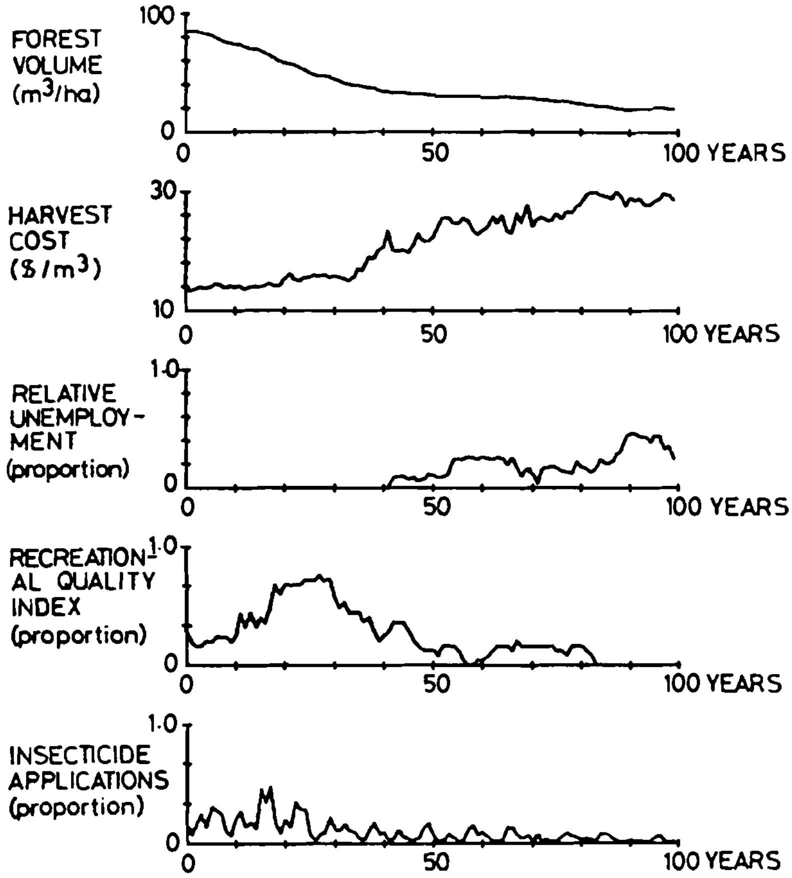

Figure 8.2. Values of the five forest-management indicators that would ensue from pursuing the historical management policy. Source: Holling (1978).

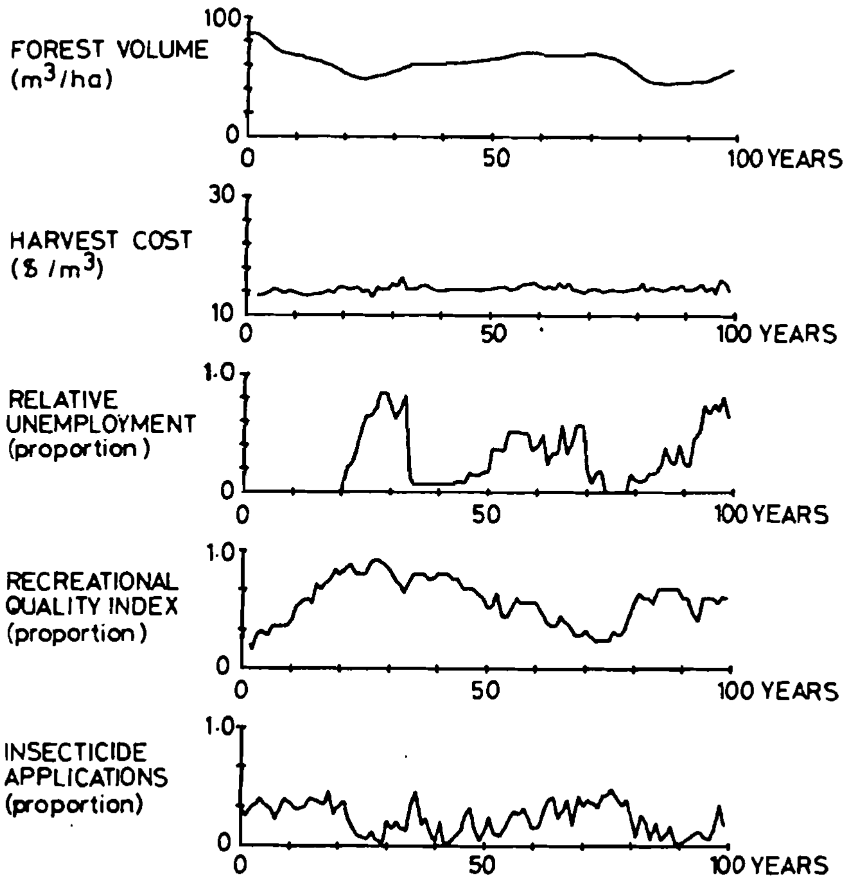

Figure 8.3. Values of the five forest-management indicators that would ensue from proposed new management rules involving new spray and harvesting policies. Source: Holling (1978).

sporadic antibudworm harvest. The "good" forest volume, harvest cost, and recreational performance have been reasonably maintained, however. Since any preventive harvest scheme seemed likely to incur this disadvantage, we searched elsewhere and attempted to reduce spraying by adding a hypothetical but realistic budworm virus to the model. As shown in Figure [8.5], this succeeded in reducing spraying substantially without radically increasing unemployment. Forest volume was better than with any other policy, and recreation was superior to any but the antibudworm harvesting policy.

9. VALUE ANALYSIS AND POLITICAL FEASIBILITY

Values and beliefs held by individuals and organizations affect analysis at all stages from problem formulation to decision and implementation. Differences in values can lead decisionmakers to advocate different actions on the basis of the same study, and, after a choice is made, can lead the implementing bureaucracy to take actions the decisionmaker did not intend.

In ranking the alternatives in preparation for a decision, or in helping the decisionmaker in ranking the alternatives, the analyst needs to discover a great deal about the decisionmaker's values. This is not easily done; "we can always ask people about their values, but in the end, we can only infer what values they appear to hold by analyzing their behavior, including their statements, in a number of situations." (Bowen 1979). Other approaches are possible. Bowen (1979) suggests such topics as the following merit more attention than they have been given: analysis of options, hypergame theory, structural mapping, personal construct theory, fuzzy sets, and a number of ideas stemming from conflict research and research gaming.

It is sometimes argued that decision problems that are "political" or value sensitive cannot be subjected to analysis. According to another view, values and facts are distinguishable and analysts (or experts, scientists, etc.) should contribute only facts to the decisionmaking process. There are also arguments for a direct involvement of analysts in "value analysis," which includes improving the

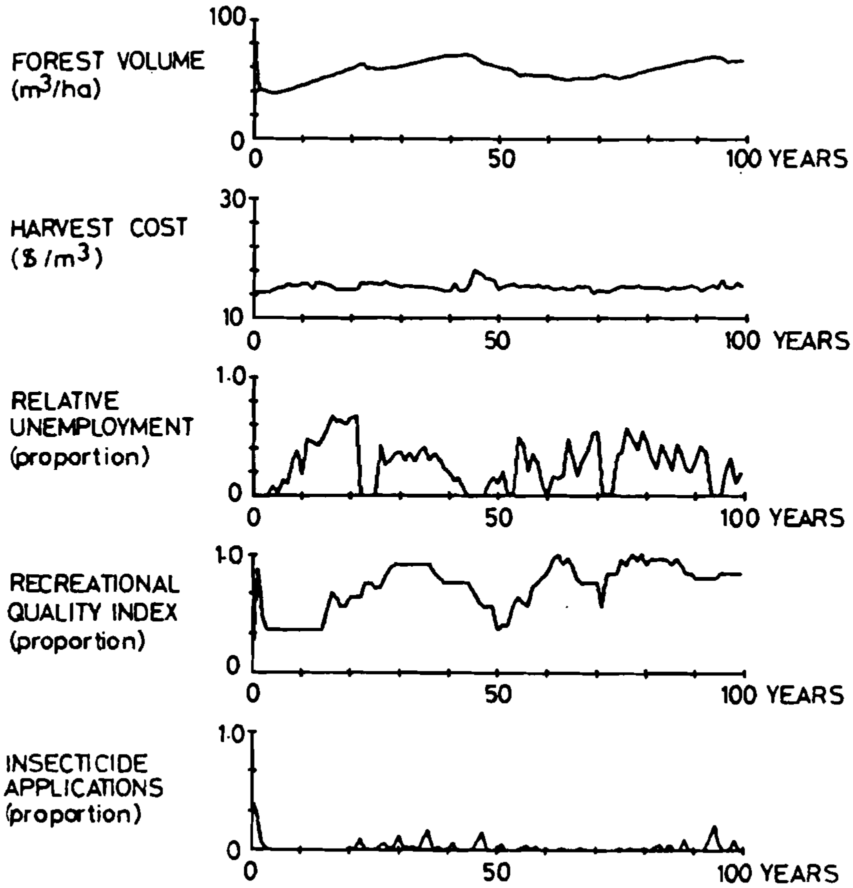

Figure 8.4. Values of the five forest-management indicators that would ensue from the proposed new management rules modified by cutting down trees threatened by budworm. Source: Holling (1978).

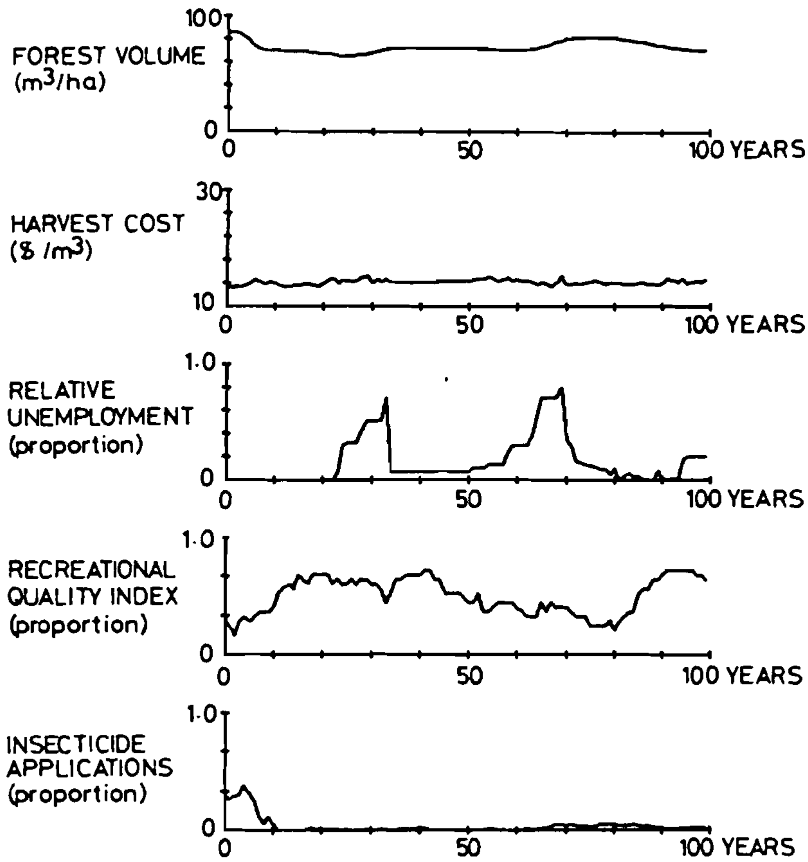

Figure 8.5. Values of the five forest-management indicators that would ensue from the proposed new management rules modified by introducing an antibudworm virus. Source: Holling (1978).

value judgment of "legitimate value judges" without usurping that function. To quote Dror (1975):

> . . . this is achieved through methodologies designed to structure the judgment field and to explicate value dimensions in a way that permits more conscious, comprehensive and explicit judgment by the legitimate value judges. These processes help them to make more 'responsible' value judgments on the basis of clarification of the fullest meanings of the involved values. Primary methods of value analysis include testing of value sensitivity, examination of value consistency, checking the completeness of the value set, explication of tacit value dimensions (e.g., time preferences and lottery preferences), value mapping, consideration of value futures, design of value and goal taxonomies, and more.

The feasibility of implementation is an important aspect when decision alternatives are compared. Depending on the decisionmaking process some alternatives may not be implementable if there are certain groups who object to them. The analysis of such aspects is sometimes called "political feasibility" testing (Dror 1968). It involves investigating the probability that a proposed action will be acceptable to various secondary decisionmakers—the special interest groups, the public, and the bureaucracy who must translate it into action. If the probability is too low, compromises can be made to increase acceptability. Analysis can help find the preferable compromises—those that increase acceptability without a proportionate loss in attainment of policy goals.

Cost-benefit and similar analyses designed to produce an economically efficient solution may encounter political opposition. For an alternative to be politically feasible, it may not only have to approximate the largest total benefit available to the affected parties as a whole, but, in addition, allocate the aggregate benefits and costs among the various interest groups in a way that reflects their political strengths. Thus, the alternative selected must be acceptable to the most influential interest groups and not too strongly opposed by the others.

When a group is asked to accept an alternative in a situation where a competing alternative would bring them greater benefit, then, if the losses can be estimated, the chosen alternative frequently can be made acceptable (and thus politically feasible), by arranging a payoff to the objecting group, say, by tax exemptions or deductions designed to benefit them specifically (Olson 1971, Starling 1979).

10. UNCERTAINTIES

In previous sections we have mentioned the existence of uncertainties, but not sufficiently emphasized their dominant role and pervasiveness in systems analysis and decisionmaking. To evaluate decision alternatives we must estimate the future consequences of various courses of action, and the future is always uncertain. The effects of some uncertainties—say those in economic, technical, and operational parameters that can be identified, measured, or at least estimated, and treated statistically—can often be taken account of in the analysis proper by actual calculation of the probabilities, or by Monte Carlo methods, or, less precisely, by using means or expected values. Sensitivity testing and *a fortiori* analysis can also be done and presented to the decisionmaker. Other uncertainties, about future environments and contingencies, and about certain activities that depend on the actions of people (now as well as in the future), are more intractable.

The decisionmaker is always confronted with a certain amount of uncertainty when presented with the results of a systems analysis. When the issue has long-term implications or involves a rapidly changing situation or one being manipulated by other decisionmakers, a number of different forecasts of the state of the world or scenarios may have to be considered. In this case, the results of the analysis as carried out for each contingency or forecast may not indicate the same order of preference among the alternatives. What then can the analyst suggest to the decisionmaker if, under one contingency with high probability of occurrence, alternative A is clearly superior, but, under another contingency of low probability but with catastrophic implications, alternative B is better?

Faced with such uncertainty the decisionmaker can, depending on the circumstances, take one or more of the following actions:

1) Delay: that is, defer his action until better information is available. Delay, of course, is not always an option and, when it is, it may be costly, particularly when competition or conflict is involved.

2) Buy information: attempt to alleviate uncertainty by supporting further research and data collection. This also involves delay and cost and may or may not improve the situation.

3) Hedge: adopt duplicate alternatives or modify an alternative to introduce greater flexibility—at a higher cost, of course.

4) Compromise: select an alternative that, while it may not be best for the contingency judged to be most likely, does not rank too low on the less likely ones.

5) Be conservative: choose the alternative that gives the best result if the environment is maximally unkind. This is the "maximin" approach, in which one resolves uncertainties by making the blanket assumption that the worst will happen.

6) Use decision theory: argue that the probabilities of the various states of nature are not completely unknown and beyond human judgment, assign probabilities to them subjectively, and then use an approach that would be appropriate for the case in which the probabilities are known.

The US military (which may have had as long an experience with systems analysis under conditions of uncertainty as any other institution) had at one time something like the following philosophy. Any attempt to determine a unique best solution to a problem involving a large number of uncertain factors, some of which may be under the influence of other decisionmakers, is doomed to failure. The aim instead should be to search out or design alternatives that perform well or even close to the best for what appear to be the most likely set of contingencies and from such alternatives, whenever it can be done, select the one that gives some sort of reasonably satisfactory performance under the more unlikely and even pessimistic circumstances.

11. RISK EVALUATION

Side effects, or negative impacts that are not direct costs to be borne by the decisionmaker,[4] may sometimes need special attention both when designing and when comparing the alternatives. Side effects are sometimes treated by imposing constraints. However, the elimination, or the reduction in the probability, of the occurrence of serious negative side effects must often be made an objective. Reductions that are below some low probability limit usually have a value.

The term risk is often used in connection with uncertain negative side-effects.[5] More specifically, risk is often associated with highly negative consequences, occurring rarely. The exact meaning of risk varies somewhat. Sometimes it means the probability of a negative consequence. In other cases it may mean the negative consequences themselves. In yet other cases, it may refer to the statistical expectation of the negative consequences. Most commonly, however, risk refers to the entire spectrum of negative consequences with their associated probabilities (see Jennergren and Keeney 1979).

Risk assessment is often thought of as consisting of two parts: risk estimation and risk evaluation. In risk estimation, one is concerned with identifying the various serious negative consequences of a project or activity, and assigning probabilities (or rates of occurrence) to those consequences. In risk evaluation, one appraises the acceptability of the risk to society.

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[4]Such negative impacts are costs to the decisionmaker in the sense that they prevent successful implementation or otherwise frustrate his decision.

[5]In economic and decision-theoretic literature, risk is sometimes used with a different meaning, denoting a nondeterministic situation where the probabilities of various events are known (see Jennergren and Keeney 1979.)

A risk evaluation sometimes includes comparisons with other risks that exist in society. This does not mean that such comparisons necessarily lead to definite conclusions. The acceptability of a risk depends on whether it is considered as a voluntary or an involuntary one, and also on the magnitude of the associated benefits. Also, the character of the risk is of importance. When two projects have risks with the same expected value (and the same benefits) people are not necessarily indifferent to them. If the worst that can happen is less serious in project A than in project B, many people will prefer A. Consequently, risk evaluation may depend on value preferences, in which case the analyst must leave the final evaluation to "the legitimate value judges."

12. DECISION PROCESSES, PLANNING, AND POLICIES

In the previous parts of this chapter, we have assumed that the guidance to be given to the decisionmakers concerns the choice between a number of alternatives that have been evaluated in the analysis. Actually, the decisionmakers may make other types of decisions. If the alternatives studied have been different designs of a public project, the first decision to be taken may not be a final decision in favor of one of the alternatives but may, for instance, be a decision:

- to study some of the designs in more detail, perhaps with new constraints;
- to accept a part of a design and keep the option open to choose later on among several alternatives;
- to include one design, perhaps vaguely described, in a plan that is to be reconsidered or reviewed later on. Certain options are thus left open regarding the final version of the project;
- to make further studies.

The decision processes that follow a systems analysis may take many different forms, and the form to be chosen may be difficult to predict. However, some information about the likely decisionmaking process is usually available to the analysts and this type of information can be important to take into account both in the design and the evaluation phases of a study. Much research has also been devoted to decision processes (Allison 1971, Simon 1957, Keen 1977, Cyert and March 1963, Lindblom 1959). Results from such descriptive-explanatory research is, of course, of considerable importance to the applied systems analyst.

It should be mentioned that a systems study does not always involve ranking followed by choice from among a number of alternatives. Sometimes, when the start of the study is a vaguely defined problem area, the output consists of no more than some tentatively defined decision alternatives or some guidelines for developing such alternatives. In the US, many systems studies are carried out in the form of "program evaluations." Here the study starts after the decision to launch a new program has been implemented and the program has been under way for some time. The problem defined at the outset may be "Has it worked as expected?" The result of the study is usually that it has not, but, more importantly, the study may suggest where to look for possible improvements (Hatry 1980). One should not expect the need for analysis to stop with implementation. Policy decisions even supported by the best of analysis seldom result in a program needing only enforcement for implementation. Models are imperfect and circumstances change. As part of the analytic effort, it should be determined as soon as possible whether the results are as anticipated, and if not, how to modify accordingly the process discovered. This monitoring and evaluating function could, and perhaps should, be undertaken by someone other than the original analyst or policymaker (Walker 1978).

13. GUIDANCE FROM THE ANALYST

The effectiveness of these various schemes for presenting the results of analysis, and for carrying out the analysis itself, depends to an extent on the decisionmaking situation. It is best when this situation approximates the rational actor model. However, a knowledge of which other model—the process-oriented view (Simon 1945), the organization-process view (Cyert and March 1963, Allison, 1971), the political paradigm (Lindblom 1959, Allison 1971), or the apprehensive man (Keen 1977)— best approximates the decionmaking situation is useful to the analyst, not so much in finding a "best" solution, but in finding a way to get that "best" solution accepted or adopted and implemented by the relevant decisionmakers and organizations other than his client. Adoption of a proposal is, in fact, usually easier to achieve than successful implementation. At the decision stage, participants may not feel it necessary to resolve uncertainties, for they can be taken care of during implementation. All that is needed may be enough support to tip the decisionmaking body in favor of the proposal. This support can be verbal and soft; implementation, however, demands that the organizations involved contribute real resources and here is where the crunch may come. But, as Majone (1980) argues, technologically sound information and factual arguments are not always enough to win acceptance. A well written report, a carefully prepared visual presentation (briefing), and persuasive communication may be needed to change the then current attitudes.

The type of guidance for decision that the analyst can give as a result of a systems analysis may be in the form of clearly specified recommendations, e.g., in favor of a given decision alternative. Whether this is a satisfactory action depends on many issues, for example,

- Have the criteria for the recommendations been thoroughly explored and agreed upon?
- Are these criteria expressible in a quantifiable manner?
- Has this quantification been based on value judgments with which the decisionmaker is in full agreement?
- Are the models used fully satisfactory to the analyst?
- Are the situations tested by the models, and the alternative options explored in these situations, reasonably complete and unquestionable?

- Are there agreed ways of weighing multiple criteria and multiple objectives?

Apprehension is sometimes said to dominate analysis (Keen 1977). Decisionmakers may sometimes learn through apprehension rather than comprehension and rely on experience rather than on understanding and analytic methods.

It is often possible for decisionmakers to agree on the action to be taken, even though they disagree on objectives. A policymaker may concur in the decision to accept a study recommendation for reasons far different from those the analyst had in mind. He may do so, for instance, because by so doing he may forestall stronger action or because he may see how to divert money that will be appropriated to implement the recommendation to other purposes.

It is not surprising then that, in general, it is safer and more satisfactory merely to provide pros and cons of better options in many situations. In dialogue with the decisionmakers, there is a wide-ranging exploration and attempt to make less vague both the nature of the problem itself and the values that the various possible options for decision have for the decisionmaker. Most systems analysts have ways of doing this, although there seems to be no general methodology: there are different approaches depending on the values held by analysts and decisionmakers and the way in which they interact.

The aim of systems analysis, while it is to improve decisionmaking, is also to make the decisionmaker more satisfied that the basis for his decision is adequate and informed. The study done must provide new insights into the problem area under discussion, and it must be structured and presented in a way that facilitates his use of the information it contains. The analysis must be seen to be relevant and its communication must be readily understood. The mode of communication, continuous or at intervals, orally or in writing, diagrammatic or in words, technical or nontechnical, mathematical or nonmathematical, will vary with circumstances, but it must be in terms familiar to the decisionmaker. Special communication aids include interactive computer modeling, scenario writing, games and game-theoretic processes, films, and even forms of counselling.

The important issue is how decisionmakers interpret the data put before them, because only some of this will be seen by them as information relevant to their decisions (for some of the pitfalls, see Lynn 1980). Their previous experience, their general world view, their reaction to variables and constraints that the analyst has or has not been able to take fully into account, and particularly their attitude towards analysis and their prior beliefs, will all affect how they use what they are offered. Analysts should strive always to understand the total environment of decisionmaking so as to provide the maximum of information and the minimum of redundant data, although initial redundancies have a habit of being useful if the decisionmaker chooses to delay his decision in one way or another.

The fact, mentioned above, that no general methodology exists for the final stage of analysis and decision, leaves one important thing still to be said. Any analyst who can make explicit, for a stated systems analysis, how the communication process used was conceived and what its successes and failures were, will have added something of value to the literature on the subject. The trouble is that, because the process depends so much on personal values and understanding of values, it is difficult to write anything down in a way that can be interpreted and used by others. It is, nevertheless, worth trying.

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