HANDBOOK OF SYSTEMS ANALYSIS

VOLUME 1. OVERVIEW

CHAPTER 4. THE METHODS OF APPLIED SYSTEMS ANALYSIS: AN INTRODUCTORY OVERVIEW

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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 4. 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.

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CHAPTER 4. THE METHODS OF APPLIED SYSTEMS ANALYSIS: AN INTRODUCTORY OVERVIEW

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1. INTRODUCTION

Usually, for a systems analysis to be undertaken, someone involved with a sociotechnical system must have a problem—or have recognized a problem situation—that is, he must be dissatisfied with the current or anticipated state of affairs and want help in discovering how to bring about a change for the better. Systems analysis can almost always provide some help, even if it does no more than turn up relevant information. The goal most frequently sought for systems analysis, however, is to discover a course of action that will bring about a desired change for the better—that is, a course that can be adopted as the most advantageous by those who have the authority to act.

Systems analysis can do more than discover ameliorative solutions, it can be used by the responsible policymakers and the people affected to present factual arguments and reliable information to help win acceptance for the solutions it discovers. In addition, after a solution is adopted, systems analysis can help during implementation to prevent the chosen course of action from being vitiated by adverse interests, misinterpretations, or unanticipated problems.

This chapter presents the methods of systems analysis in so far as they relate to discovering better solutions; advice as to how it can be used as an instrument of persuasion or to aid in implementation is postponed to later chapters. The problems of winning acceptance for a course of action and then implementing it must, nevertheless, be considered during the process of seeking and evaluating a solution, for a proposed course of action that is not acceptable to those who must approve it, or that cannot be implemented for political or other reasons, cannot be a solution.

Although a systems analysis may be carried out without a specific decisionmaker in mind, this is not its most effective use. This chapter discusses the approach as if the analysis were being carried out for a single decisionmaker who commissioned it. This decisionmaker is assumed to be an individual who wants to make his decisions rationally by taking into consideration the probable consequences of each of his available courses of action, selecting the "best" by balancing the extent to which these actions achieve his objectives and possible other benefits against their costs. (As a simple extension, we can also consider the single decisionmaker to be replaced by a relatively small group with roughly similar preferences.) The analyst's basic procedure is to determine what the decisionmaker wants, search out his feasible alternatives, work out the consequences that would follow the decision to adopt each of the alternatives, and then either rank the alternatives in terms of their consequences according to criteria specified by the decisionmaker or present them with their consequences to the decisionmaker for ranking and choice in some framework suitable for comparison.

In reality, the decisionmaking situation—as the examples discussed in Chapters 1 and 3 show—is rarely so uncomplicated; the person for whom a study is done is usually no more than a key participant in a decisionmaking process who uses the results of the analysis as evidence and argument to bring others to his point of view. The decisionmaking model of the previous paragraph is not therefore an adequate model for decisionmaking in the public sector or for policy and strategy formulation where large complex systems are concerned. These latter decisions cannot be separated from the managerial, organizational and/or political situation in which they are made (Mintzberg and Shakun 1978) and the model we are assuming for the decisionmaker (called the "rational actor model" or Model I in Allison (1971) must be supplemented or modified by bringing in organizational and political considerations (Allison 1971, Lynn 1978, Rein and White 1977). Nevertheless, as Allison (1971, p.268) remarks: "For solving problems, a Model I-style analysis provides the best first cut. Indeed, for analyzing alternatives and distinguishing the preferred proposal, there is no clear alternative to this basic framework". Therefore, we throughout this chapter stick to the basic, unsophisticated view of the decisionmaking situation.

As an example to illustrate the basic procedure, assume that a legislative committee wants to propose legislation to increase highway safety. It is willing to consider measures of three types: a requirement for devices to make the use of seat belts automatic, lowering the maximum speed limit and enforcing it more strictly, and establishing higher standards for issuing drivers' licenses. They ask the legislative analyst to carry out a systems analysis.

In the simplest systems analysis approach (which is identical to the logic of choice paradigm defined by economists, e.g., Hitch and McKean 1960) it is useful to consider the problem in terms of these elements:

Objectives. What the decisionmaker desires to achieve. In the example, it is increased highway safety, a concept that the analysis must make more precise.

Alternatives. The means by which it may be possible to achieve the objectives. In the example, there are three kinds of alternatives.

Costs. The cost of an alternative is the totality of things or actions that must be given up to acquire the alternative, including money, the use of personnel or facilities for other purposes, and so on. For example, stricter enforcement of the speed limit would require more police officers, who must be hired and trained or taken from other tasks; in either case the action would result in a cost to be associated with any speed-control alternative.

Performance Scales. A performance or effectiveness scale is a device for indicating the extent to which an objective is attained. It provides a tool for evaluating the performances of alternatives in achieving the objective. For example, it can be agreed to measure the increase in highway safety by the decrease in annual traffic fatalities. Often there are many possibilities, and the choice of a suitable scale can be a problem in itself.

Performance. The performance or effectiveness of an alternative is the position it achieves on the scale.

Criterion. A rule for decision that specifies in terms of performance and cost how the alternatives are to be ranked. A common one is to rank the alternatives in decreasing order of performance for fixed cost.

Models. Explicit models are used to describe, first, a context or state of the world in which each alternative might be implemented and then to estimate for each alternative the performance, costs, and other consequences that follow from its implementation.

These models are not the only or even the first use of models in a systems approach; they are, however, the most prominent for they are likely to be elaborate and programmed for a computer while the other models are often merely implicit mental models. In fact, more than one model may be needed to estimate the impacts if the alternatives are of different types; a model to estimate the monetary costs of doubling the strength of the highway patrol must differ from a model for predicting that the effect the presence of this increased force on the highways will have on traffic fatalities.

In general, a model is no more than a set of generalizations about the world, a simplified image of reality that may be used to investigate the outcome of an action without taking it or the behavior of a system without altering it. It is made up of the factors relevant to the problem and the essential relations among them. A model may take many forms, among them, a set of tables, a series of mathematical equations, a computer program, a physical simulation (rare for systems analysis), or most often in everyday life merely a mental image of the situation in the mind of someone contemplating an action, rarely made explicit with a sequence of logical arguments. In one form or another models must be used throughout any analytic process. (A more complete discussion of systems analysis models is postponed to Chapter 7 and to Volume 2.)

The objective and systematic approach by means of an explicit model is needed for predicting the impacts because, in most systems-analysis problems, the factors are so numerous and their interrelations so complex that intuition and simple mental models are not good enough. Some highway safety measures, for instance, have counterintuitive effects: certain crash barriers reduce fatalities but increase some kinds of injuries. Others have interdependencies that strongly affect their joint performance: an energy-absorbing bumper, for instance, would appear to save more lives if it were installed alone than in combination with a shoulder harness (Goeller 1969).

In our example, an early problem for the analyst is to find a way to turn the vague goal of "increased highway safety" into something of a more operational character, or, in other words, to settle on a way to measure it. One possibility might be to use the reduction in the annual number of fatalities as such a measure; another might be to use the reduction in the annual (monetary) cost of highway accidents to the victims. There are other possibilities and the full list may be a long one. Unfortunately, this choice may affect critically how the alternatives are ranked. For instance, while strict enforcement of the speed limit may reduce fatalities, a serious consequence of high-speed collisions, it may have little effect on the number and cost of "fender-bending" accidents, which are numerous and costly to the participants, while more stringent requirements for a driver's license may reduce both significantly.

Another task for the analyst is to examine the alternatives for feasibility. It may turn out, for example, that, in the current state of the art of automotive engineering, the alternative of automated seat belts is not feasible, say, owing to public acceptability considerations. Similarly, the analyst may be able to find out that the passage of legislation to lower the current maximum speed limit is not politically feasible. This alternative may then have to be reduced merely to stricter enforcement of traffic regulations, dropping any thought of lowering the maximum speed limit.

The analyst will also want to search for and examine alternatives not on the original list—such things as better emergency ambulance service, eliminating unguarded railroad crossings, changed car design, and others—for these may promise increased highway safety at no greater cost. Indeed, as we shall emphasize in Chapter 6, the discovery, invention, or design of new and better alternatives is often the real pay off from systems analysis.

In predicting the impacts associated with the alternatives, as we remarked earlier, the analyst may have to use radically different means or methods. A model to show the effect of improved driving skills on fatalities can be considerably different from a model to predict the way a lower speed limit affects them. On the other hand, predictions for both cases may be obtained statistically from experiences in other jurisdictions with similar driving conditions, although a definition of similar may not be easy to decide. Also, to compare alternatives, various different futures may have to be considered, with assumptions made about the effects of a petroleum shortage on automobile traffic, changing car preferences, population movement, and other exogenous factors beyond the decisionmaker's control that can affect the outcome.

One run-through of the set of procedures is seldom enough; several cycles or iterations usually improve confidence in the results. For instance, it may be discovered that the impacts of certain alternatives that restrict automobile drivers produce effects that spill over onto entirely different groups of people, say those that ride public transportation, in ways that differ from alternative to alternative and were not anticipated when the alternatives were first formulated. Additional emergency medical services for traffic-accident victims, for instance, may increase the burden on the supply of doctors and hospital beds, and hence the analyst may have to enlarge the analysis to include aspects of the medical system and/or the public transportation systems and carry out additional calculations.

With this background, we now turn to a more detailed and thorough description of the procedures we have suggested.

2. A FRAMEWORK FOR SYSTEMS ANALYSIS

Objectives, alternatives, and choice. Analysis to assist someone (called here the decisionmaker) to discover his "best" course of action may, in general, be considered as an inquiry into three basic questions:

1) What are his objectives?

2) What are his alternatives for attaining these objectives?

3) How should these alternatives be ranked?

As defined earlier, the *objectives* are what a decisionmaker seeks to accomplish or to attain as a result of his decision, and the *alternatives* are the means available to him for attaining the objectives. Depending on the problem, the alternatives may be policies, strategies, designs, actions, or whatever it takes to attain what is wanted. *Ranking* implies a listing of the alternatives in order of desirability considering the objective and the values the decisionmaker puts on the various outcomes that follow as a consequence of their implementation.

The three basic questions expand into further questions when we consider that:

– to be able to identify the feasible alternatives, one must know not only the objectives but also the boundaries within which the decisionmaker is free to act, that is, the *constraints;*

– to determine the *consequences (impacts)* that follow from the choice of an alternative one must consider that the future is uncertain.

– to take account of the uncertain future, we need a *predictive model* showing what will happen if the decisionmaker chooses an alternative, given each particular contingency, or alternative future *state of the world* considered.

— to rank the alternatives, it is necessary to investigate the decisionmaker's *value system* and possibly that of other parties whose opinions the decisionmaker may wish or be forced to consider.

Different models, from very rough to very precise, may be used as we proceed in the analysis from the first rough screening to eliminate the clearly unsatisfactory alternatives, through various iterations to reach the final ranking.

A framework for analysis. Systems analysis to aid decisionmaking, like science, is a craft activity (Majone 1980). The way in which a study is organized and carried out depends on many choices by the analyst that are often based on little more than experience and intuition. An approach that may produce valuable insights when used by one analyst may yield faulty or misleading conclusions when used by another. Nevertheless, every systems analysis will be composed of certain more or less typical activities that have to be appropriately linked to each other. From this point of view, we can present a first approximation to the systems-analysis process schematically as in Figure 1, where the main components are represented (other breakdowns are, of course, possible):

1) Formulating the problem.

2) Identifying, designing, and selecting the alternatives to be evaluated.

3) Forecasting future contexts or states of the world.

4) Building and using models for predicting the consequences.

5) Comparing and ranking the alternatives.

These components encompass several additional activities, two of which are indicated in Figure 1: *determining the constraints* and *determining the decisionmaker's values and criteria*. Among those omitted from the figure, but needed for every analysis, are *data collection and analysis*, and *communication between analyst and decisionmaker*. Too, this figure does not show the followup activities that may ensue from a systems analysis study whose recommendations are adopted, or the evaluation work that may accompany the implementa-

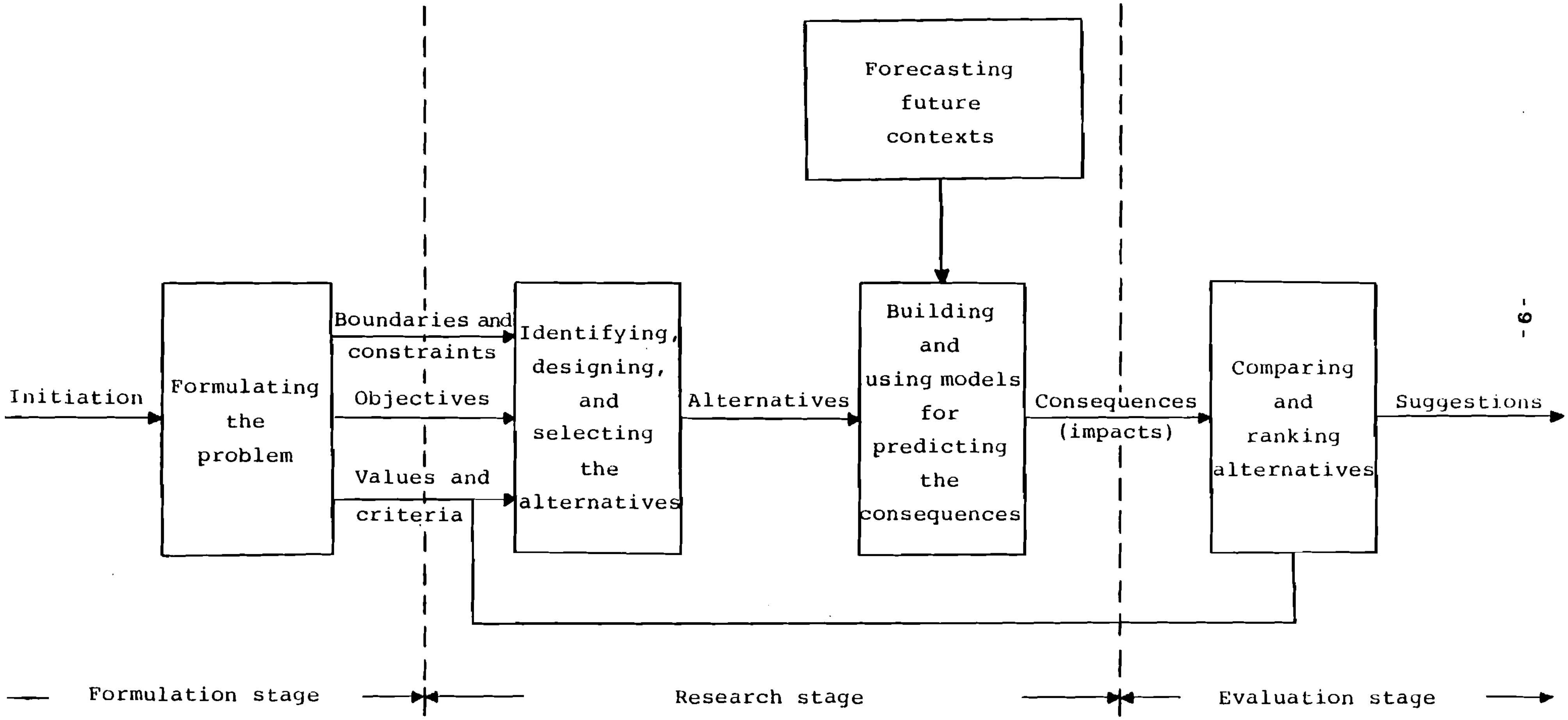

Fig. 1. The systems-analysis procedure

tion process.

The solid lines in Figure 1 show the principal flows of information from activity to activity.

Iteration and Feedback. In most investigations few of the component activities depicted in Figure 1 can be performed adequately in a single trial. Iteration is needed; that is, preliminary results, or even an incomplete version of the final result, may force the analyst to alter initial assumptions, revise earlier work, or collect more data. A decisionmaker, for instance, may not settle on his objectives until he has a good idea of what he can do, or he may want to impose additional constraints after he discovers what some of the impacts are.

Figure 2 shows some of the typical iterations and feedback loops in a systems analysis study.

One feedback loop is from the impacts (the consequences) to designing alternatives. By this loop one modifies or refines some alternatives, typically by adjusting their parameters, and eliminates others. The process of refinement through iteration may be done separately for each alternative; it is sometimes based on a formal optimization procedure.

Another typical loop is the one from the model results back to problem formulation. This iteration is necessary because it is usually impossible to set the objectives and determine the constraints with precision before knowing something about their implications. A first cut may also suggest a need for redefining the alternatives; in fact, we may have to design an entirely new set of alternatives.

Furthermore, we may be dissatisfied with the results obtained under our current assumptions and constraints. Iterations may be carried out to see what the "cost" of the constraint is, that is, how much more of the objective could be obtained or how much the monetary cost could be lowered if a constraint were weakened. We may eventually negotiate removing, or softening, some of the constraints. If this is not possible, lowering the objectives of the decisionmaker

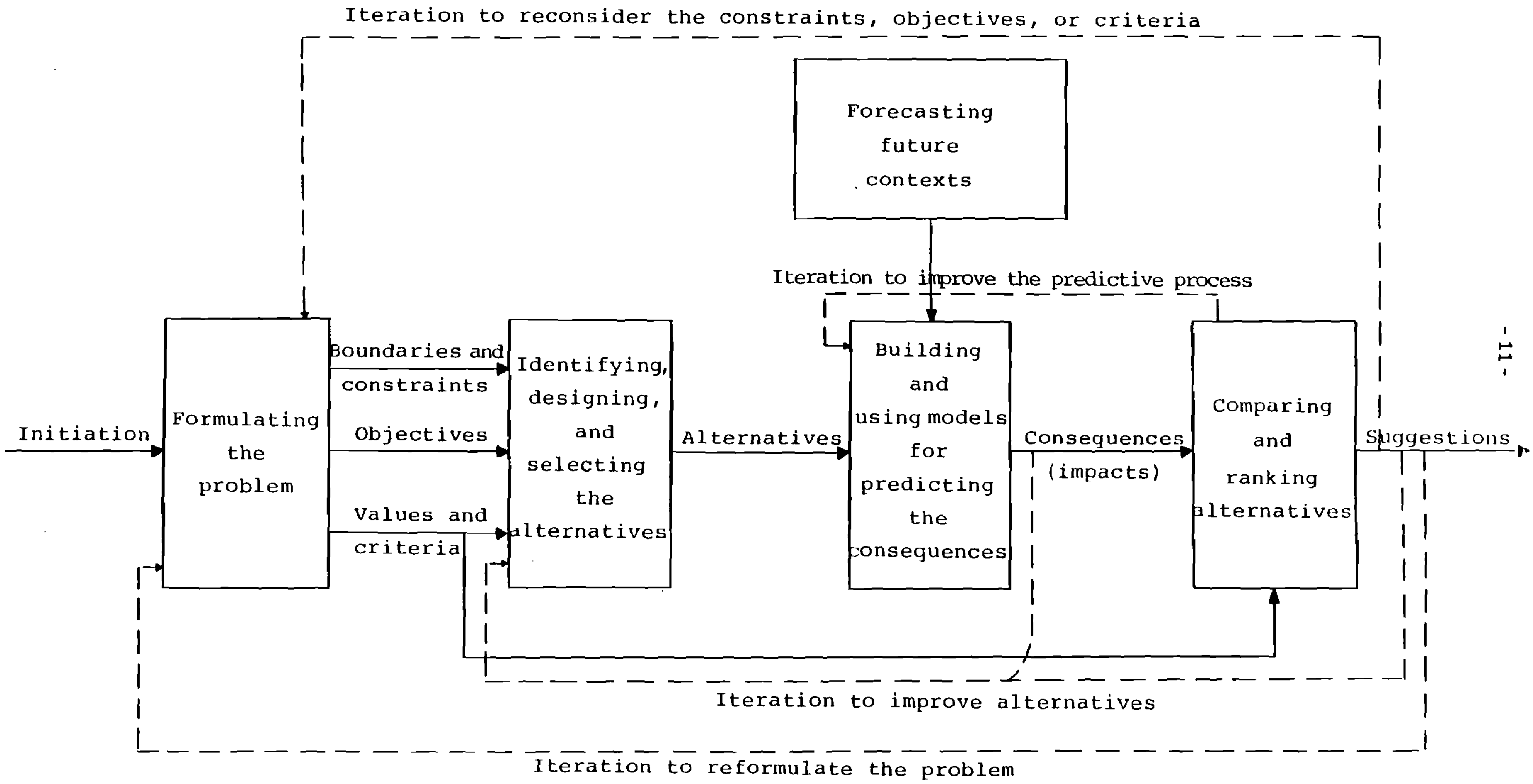

Fig. 2. The systems-analysis procedure with iteration loops

may have to take place.

Another important purpose of iteration is to improve the models used for prediction, a process that may actually result in simplification, as elements and relations originally thought to be significant are found to have negligible effect.

Analysis does not necessarily end, even when iteration through these stages no longer brings significant improvement and the various courses of action open to the decisionmaker have been compared, ranked, and presented for his choice. As mentioned in the introduction, an analyst, although not necessarily the original one, may also be needed to provide assistance with additional tasks—helping to resolve unanticipated problems arising during discussions with other decisionmakers or arising during implementation of the decisions, and, even much later, after the process of implementation has succeeded (or failed), evaluating the entire procedure.

Although most of the infeasible alternatives should have been eliminated during the earlier stages of the analysis, the implementability of a course of action may remain a question even after implementation is well under way. One reason is that the final decision may not have been presented in a way adequate to instruct and motivate those who have to execute it and who may have their own ideas as to how to interpret it. There may also be considerations that are important for implementation, but which were not important to the choice between alternatives and which, in order to keep the problem workable, had not been spelled out in detail. But the passage of time is the most frequent cause.

Implementation may not start or may continue for so long after the analysis was completed that changes in the state of the world different from any of those forecast in the analysis may require the implementation process to be modified. What was "the future" during the analysis becomes the present, and an analyst may be needed once again to modify a program that may now be partially inappropriate. Indeed, the need for complete reanalysis can never be totally dismissed.

Finally, the analyst may be called on to assist the decisionmaker to evaluate the progress of the implementation, for, by virtue of his previous studies of the problem and his knowledge of the cause-effect relations, he may be able to detect the reasons for discrepancies and deviations from the effects originally intended.

Communication. Communication is an important factor for the success of systems analysis. Communication with the decisionmaker is vital, for his advice and judgments are indispensable at all stages of the analysis and he must not be surprised at the end. The results are much more likely to be accepted and used if he participates in producing them. Throughout the procedure there should therefore be a continuous dialogue between the analyst and the decisionmaker,including his staff. This dialogue influences the decisionmaker's attitude toward the problem even before the study is finished, and helps to make sure that the important facets of the real situation are considered. The constant exchange of information also gives the staff a sense of participating in the study and means that the results will not come them cold, with a sense of shock—a circumstance that can lead to their rejection.

Another reason for continuing communication is that the initial problem formulation can never be complete and all-inclusive. As mentioned above, preliminary results of the analysis will modify the initial views, new questions will arise, and the preferences, constraints, and time horizons may change.

Stages of analysis. There are many more linkages between the component activities of systems analysis than those shown in Figure 2. Despite this complex interdependence, it is convenient to discuss the procedure in three *stages*:

A. Formulation

B. Research, comprising

- Generating and investigating alternatives
- Forecasting the contexts

- Determining the consequences

C. Evaluation

We shall characterize the *stages* of systems analysis, as well as the more important *component activities*, in more detail.

Partial analysis. Before doing this, however, we note that not every systems-analysis study contains every stage or component. Some studies may be useful even though they lack some of the steps in the very general schematic presentation in Figure 1; we refer to such studies as *partial analyses*. Here are some typical examples:

– Forecasts of the future state of the world, where no immediate action by a decisionmaker is contemplated; for example, econometric forecasts, which analysts are asked to provide for governments or large industrial companies.

– Impact analysis, i.e., determining all impacts, or even merely a certain class of impacts, of a proposed course of action. For example, studies to determine the consequences of a particular technological development on the environment may involve no comparison or ranking.

– Decision analysis, that is, assistance in making a choice among a limited number of well specified alternatives, whose consequences are assumed to be known. Here the analysis merely provides a framework for ranking these alternatives. A typical instance is the choice of an industrial project from among several available alternatives, or a decision to buy equipment from competitive suppliers.

In these examples, not all of the component activities of a complete systems analysis are carried out by the analysts. On the other hand, there are cases where all the activities are present, but where some of them need to be emphasized more than others.

Whenever a partial analysis is commissioned, the assumption is that someone, usually the decisionmaker, is providing the missing aspects. Generally the decisionmaker will do this purely by judgment or assumption for, although some decisionmakers have the ability to carry out the required analysis themselves, they rarely have the time.

3. PROBLEM FORMULATION

Goals and difficulties. Generally speaking, problem formulation (the subject of Chapter 5) implies isolating the questions or issues involved, fixing the context within which these issues are to be resolved, clarifying the objectives, identifying the people to be affected by the decision, discovering the major operative factors, and deciding on the initial approach to be taken in the analysis. It is expected that problem formulation will provide, among other things:

(a) a preliminary statement of the objectives, and ways to measure their achievement,

(b) a specification of some promising courses of action, i.e., the alternatives,

(c) a definition of the constraints,

(d) an anticipation of the type of consequences to be expected, the measures of their importance, and a definition of the criteria for choice.

Problem formulation should result in specifying the limits of the inquiry, the questions to be addressed, and the aspects of the real world to be included, in what time frame, with what analytic resources. The scope of the problem can be limited by limiting the number and type of alternative actions to be considered but it is not possible to confine the effects of these actions within neat boundaries.

As one aspect of problem formulation, the analyst must consider the analytic approach to be taken, which, of course, depends on the information wanted and the type of problem. For example, if the decisionmaker has been assigned a fixed budget, the analysis may take the form of an attempt to discover the alternative, attainable with the given budget,that will enable him to achieve, or most nearly achieve, his objective. Alternatively, it may be that progress is required in correcting some undesirable condition. The analytic objective may then become to discover the point at which the marginal benefits of corrective action become equal to the marginal costs. Another possibility is that the analysis should be directed toward ascertaining whether some proposed course of action yields a sufficiently high rate of return on the required investment to make it attractive.

As the study progresses and more information becomes available, the analytic approach may have to be modified.

Formulation involves critical assumptions made by the analyst because alternative formulations leading to different outcomes may seem equally tenable. The decisionmaker's advice is crucial here in deciding which formulation is right. The effort spent restating the problem in different ways, or redefining it, clarifies whether or not it is spurious or trivial, and may, indeed, point the way toward a solution. Until the problem has been defined and the issues clarified, it may not be clear that the study effort will be worthwhile. The great pitfall is that the result depends on the underlying assumptions made by the formulator and he and the decisionmaker may not be aware of what these are.

Among the difficulties of problem formulation these usually stand out:

(i) No issue is isolated; every system is linked to other systems and it is thus part of a larger one. There is therefore a mutual dependence of the objectives, constraints, and consequences.

(ii) We cannot set the objectives firmly unless we know what can be achieved, that is, until we know—with reasonable accuracy—the results of analysis.

(iii) The objectives, as well as the measures of value and the criteria for choice, are highly subjective and depend on the decisionmaker's preferences, which may be both difficult to assess and varying over time. This applies, in particular, to high-level objectives, which are seldom stated in any sort of operational form.

For many reasons, the problem-formulation stage can be seen as a small-scale systems analysis study in itself. It may involve a very broad range of inquiries into the hierarchies of objectives, the value systems, the various types of constraints, the alternatives available, the presumed consequences, how the people affected will react to the consequences, etc. The models used for prediction, however, are still crude and may be entirely judgmental. A systematic approach to problem formulation through some fairly formal device such as an "issue paper" may be desirable; Chapter 5 describes this device and provides other information about problem formulation.

Objectives. The objectives are what a decisionmaker seeks to accomplish or to attain by means of his decision, that is, by the course of action he decides to implement.

The analyst has to determine what the decisionmaker's objectives actually are; Chapters 5 and 8 give a more thorough discussion of the difficulties that are frequently encountered at this stage. For the present purpose, we state merely that an objective may be specified in a more or less general fashion, may be quantified or not quantified, and is usually a step in a *hierarchy of objectives;* one speaks about different *levels* of the objectives.

Often the levels of objectives differ according to the time horizon. For example, in economic planning, or in corporate planning, there is a hierarchy of short-term and long-term objectives that have to be consistent with one another.

The fear of setting objectives that may prove to be inconsistent with higher-level, more comprehensive objectives may lead a decisionmaker to specify an objective at too high a level to be helpful in the analysis. For one reason, the courses of action that are required to attain this higher level objective may not be his to choose.

It is the objectives that suggest the possible alternatives, for, to be considered an alternative, a course of action must appear to offer some chance of attaining the objectives. As more information becomes available and the original alternatives are proved to be infeasible, new alternatives must be discovered. If these too prove infeasible, the decisionmaker may have to change his objectives.

Unless the objectives are correctly and clearly spelled out, the rest of the analysis will be misdirected—wrong and ineffectual alternatives will be proposed that do not favorably affect the problem that generated the analysis. To define objectives it is often helpful to call on several people not involved with the problem under analysis, particularly outsiders skeptical of what they think the decisionmaker is trying to do. Another possibility is to start by specifying a measure of performance that seems appealing and then examining the objectives it serves. In effect, one keeps trying to answer such questions as: What is the decisionmaker really trying to accomplish? What ultimate good result is desired? For example, what objective is really served by lowering the speed limit?

We would like to be able, for the sake of analysis, to measure the degree to which an objective will be attained by a course of action under consideration. For this reason, if the original objective cannot be quantified, one must often define a *proxy objective:* a substitute that points in the same direction as the original objective, but which can be measured. For example, "income" might be be a proxy for "quality of life." Sometimes the proxy is one dimension of a multi-dimensional objective, as when "reduction in mean travel time" is used as a proxy for "improved transportation service." In such a case it may be better to use a weighted index in which all dimensions are represented (Raiffa 1968).

If the degree to which the objective has been attained is measurable in some sense, one can set a target value; for example, "achieve an average travel time of 40 minutes." Often, to be more flexible, we prescribe an interval, for example, "achieve an average travel time of less than 45 minutes," which leaves more freedom for the choice of alternatives.

In many cases, the decisionmaker seeks multiple objectives, which frequently contribute to a single higher-level objective, although we may not be able to measure how much each individual objective contributes.

An example of such a situation is "the quality of urban life," as a higher-level objective to which several component objectives, such as better housing, less air pollution, reduced travel times, less aesthetic discomfort, and others, contribute. If we cannot work out the relative contribution of each factor, we ordinarily seek alternatives that improve, in a measurable degree, all, or the majority, of the contributing component objectives, leaving the ultimate ranking to the decisionmakers.

Multiple objectives are usually *competitive*, i.e., an alternative designed to bring about maximum improvement in one of them is associated with a deterioration in some of others, because of limited resources or other constraints. For example, a desire for a decrease in noise pollution may force undesirable constraints on the rapidity of urban transportation.

To reconcile multiple objectives may present a serious problem, as treated in Chapter 8 and in numerous publications (for example, Raiffa 1968; Keeney and Raiffa 1977; Bell, Keeney, and Raiffa 1976).

Values and criteria. A course of action will have many consequences, some contributing to a particular objective, some detracting, with still others being side effects, that is, consequences that are neutral with respect to the objective, but possibly with productive or counterproductive implications. If we wish to say how good an alternative is, we need a *measure of value* for each of its significant consequences. If we want, moreover, to be able to compare different alternatives in order to indicate a preference, we need *criteria* for ranking them.

A measure of value is subjective. The same thing may be of different value to different people. In practice, the values of the decisionmaker override those of all other interested parties, because he will decide whether or not to take a given course of action. But, in all cases, the preferences of the persons or groups the decisionmaker is serving, or of those who will be affected by his decision, must be considered, for he may not only want to take them into account, but feel it necessary in order to implement what he wants done.

For example, consider the air pollution to be caused by a future industrial plant. If no pollution standards or penalties exist, does this mean that the industrial manager can neglect pollution, although he knows the damage it will cause? Clearly, he cannot do so without considering the cost of the decision to do so, because the people affected may, in one way or another (say through their influence on future standards imposed by the state) affect the profits of the plant. It is the duty of the analyst, in such a case as this, to indicate the impact of pollution on those who will be affected, and somehow to transfer their subsequent dissatisfaction to the decisionmaker's balance sheet.

The values held by the decisionmaker, that is to say, the importance he attributes to the various impacts, determine the criteria for ranking the alternatives; hence the decisionmaker's values must be investigated at an early stage.

The aim of the systems analyst, especially when working for a client, is not to say what the decision *ought* to be; he should only say that, given the criterion and his best knowledge about the client's preferences and those of the other impacted parties, the alternatives should be ranked in a certain order. As soon as the analyst makes recommendations, based on his own values, as to what the decision should be, the analyst is abandoning his role as an analyst and becoming an advocate. This may be an appropriate role in some cases, but when assumed the analyst should make clear what he is doing.

More attention to the problem of criteria is given in section 7 and in Chapter 8.

Constraints. Constraints are restrictions on the alternatives; they may be physical properties of systems, natural limitations, or politically imposed boundaries that do not permit certain actions to be taken. Thus, the constraints imply that certain consequences cannot be obtained and that certain objectives cannot be achieved. The alternatives, consequences, and objectives that are not prohibited, directly or indirectly, by the constraints are referred to as feasible.

Some examples of possible constraints are: physical laws, natural-resource limitations, available manpower, existing legislation, accepted ethics, allocated investment money.

Some constraints will be discovered during problem formulation, but others not until the impacts are known; some political or cultural constraints may not be imposed until implementation has started and opposition has had time to develop.

The question of feasibility is an important, if not dominant, component in systems analysis, and usually a difficult one to deal with. Finding a feasible alternative, just any feasible alternative, may be a satisfactory result for analysis. An investigation of the feasibility of actions or objectives is referred to as *feasibility analysis*.

There are many different kinds of constraints. Some are permanent and can never be violated (physical laws, global resources). Others are binding in the short run, but may be changed by the passage of time or removed by invention or by improvement in the state of the art. Still others are man made, set by the political situation or merely by the decisionmaker's tastes.

There are different constraints at different levels of decisionmaking. Usually the lower the level of decision, the more constraints there will be to consider. For example, an analysis of alternative urban transportation systems would have to consider a cost constraint, air and noise pollution standards, and perhaps also an employment constraint. All these are constraints imposed by decisions made at a higher level, usually of the resource-allocation type, and not directly by the available resources.

Depending on their character (objectively existing, or imposed by a decision) the various constraints are treated in essentially two different ways. Some constraints are *rigid* or *unquestionable;* to this category certainly belong the constraints of natural laws and global resources. We have already indicated, however, that resources may be rigid only at a particular decision level. For a city, or an industrial plant, the resource constraints are often the result of an allocation decision and may therefore be considered *elastic* or *negotiable*. By elastic or negotiable constraints we mean ones that may, in principle, be changed by a higher-level decision if the analysis provides a good case for the change. Providing the case may consist, for example, in showing how much more of the objective can be gained if the constraint is changed by various amounts. A calculation of this kind is a form of marginal analysis. It may happen, for example, that a slight lowering of the standard of admissible pollution would cause a substantial reduction in the cost of producing an industrial product. Analysis of this type can thus determine the cost of the constraint; we should not forget, however, that expressed in this way, it is the cost of the constraint to the polluting party, not to those who are being polluted.

As already said, it cannot be expected that all constraints, and much less so the feasible sets that result from the constraints, will be revealed at the initial stage of problem formulation. Nevertheless, it is important to determine at least the most influential constraints initially. With respect to those resulting from higher-level decisions, it is desirable to get some feel as to how firm these constraints are and, in particular, whether they are defined and definite for the whole time horizon. Otherwise, the analysis may investigate actions or alternatives that will be entirely inappropriate.

For a further discussion of constraints, see Majone (1978).

4. GENERATING AND SELECTING ALTERNATIVES

It can hardly be overstressed that generating alternatives is, in systems analysis, an exercise of creativity and imagination appropriately tempered by a thorough and broad knowledge of the issues. The alternatives that have to be considered in a particular case may be wide-ranging and need not be obvious substitutes for each other or perform the same spectrum of functions. Thus, for example, education, recreation, family subsidy, police surveillance, and low-income housing (either alone or combined in various ways) may all have to be considered as possible alternatives for combating juvenile delinquency. In addition, the alternatives are not merely the options known to the decisionmaker and the analysts at the start; they include whatever additional options can be discovered or invented later.

The set of potential alternatives initially includes all courses of action that offer some chance of attaining or partially attaining the objectives. Later, as the constraints are discovered, the set is reduced. Whenever it is sensible to do so, the "null" alternative, the case of no action, should be included for the purpose of comparison.

In most cases, a number of alternatives are explicitly suggested by the decisionmaker, i.e., they are defined by a more or less detailed enumeration of their specific characteristics. Others are discovered or invented by the analysts.

Certain properties of the alternatives, while they may not be specifically demanded by the objectives and criteria, as stated by the decisionmaker, nevertheless are important and likely to be considered later in his evaluation and hence should be considered by the analyst in their design.

One of these, an almost indispensable feature of an acceptable alternative, is its insensitivity (robustness), measured by the degree to which attainment of the objectives will be sustained despite disturbances encountered in normal operation, such as varying loads, changing weather conditions, etc. In urban transportation, insensitivity could mean, for example, that the average travel time does not greatly increase even when the peak-load and street traffic are increased by 25% or more.

Another feature important for many applications is reliability, which is the probability that the system is operational at any given time, as opposed to being out of order. In some cases, it is important for the proposed system never to fail; in others, that it not fail for a time longer than some threshold value; and in still other cases, a failure is tolerable if it can be repaired quickly; this feature, in turn, brings us to the question of maintenance and, consequently, logistics.

A system is vulnerable if damage or failure of an element causes considerable trouble in meeting the objectives (vulnerability does not mean, or does not necessarily mean, complete failure). In the urban transportation example, a bus system is vulnerable to snow storms. One would like an alternative with low vulnerability.

Flexibility is a property exhibited by an alternative designed to do a certain job that can also be used with reasonable success for a modified, or even an entirely different, purpose. It is important to have a flexible alternative when the objectives may change or when the uncertainties are very great. For example, for transferring fuel, rail transportation is more flexible than pipelines.

In addition, each alternative that survives the other feasibility tests must be examined with implementation in mind. Some alternatives will be easier to implement than others; those impossible to implement must be eliminated and the cost of implementation associated with each of the others must be taken into account.

Generating alternatives is above all a craft or art, an exercise of imagination, creativity, criticism, and experience. It is the diversity of alternative ways of attaining an objective, so often encountered in socio technical system problems, that calls for creativity and ingenuity rather than for a deep knowledge of formal tools. Therefore, what we say below can only be a loose guideline, a framework, which may be of assistance in some cases and useless in others.

Whenever a diversity of means exists to achieve the objectives, generating and selecting alternatives are best done in steps or stages. Initially, it is appropriate to consider a fairly large number of possiblities as alternatives; any scheme that has a chance of being feasible and of meeting the objectives should be investigated. At the beginning, it is good to encourage invention and unconventionality; foolish ideas may not appear so foolish when looked at more closely. It may often be advisable to reach beyond the less rigid constraints, to broaden the scope of the study outside the limits that were initially set by the client. Compare, for instance, Ackoff (1974).

The many alternatives that are considered initially cannot be investigated in detail. It would be too costly and, above all, excessively time-consuming. Some kind of screening, based on expert judgment, evidence from past cases, or simple models, can often be used to select a few of the alternatives as more promising for the next stages of investigation. It may, for example, be possible to reject some alternatives by dominance: i.e., because another alternative exists that is better in at least one aspect and equally good in all the remaining significant aspects.

The stages that follow the initial scrutiny should involve an increasing amount of quantitative assessment. At first, the assessment of the consequences of each alternative may still miss many details, but it should be adequate to permit rejecting a fair percentage of the original alternatives on the ground that the other cases are more promising.

The last stage of the selection procedure should investigate relatively few alternatives, but in considerable detail. These alternatives should be serious candidates for implementation. At this stage every effort should be made to assess each alternative as accurately as possible, and each one may have to be fine-tuned to yield the best results possible. At this stage, systems analysis overlaps with "systems design" or "systems engineering," where–for example, for an industrial plant–the job is to determine all specifications for the consecutive design of the particular parts of the plant.

Fine tuning is an activity that may, in appropriate cases, make good use of mathematical models. The problems are usually well defined when fine tuning is appropriate and setting the details may be ideal for formal procedures for optimization, such as linear programming.

As can be seen, we favor a procedure of step-by-step rejection of alternatives rather than one of focusing on selecting the best alternative in a single operation. This procedure has some rationale; first, the alternatives that are shown to be infeasible can be rejected (irrespective of what they promise in terms of benefits); next, the alternatives that can be shown to be markedly sensitive or vulnerable can be rejected, etc. It is, in many cases of judgment, easier to agree on rejection than to agree on positive selection.

5. FORECASTING FUTURE STATES OF THE WORLD

Forecasting in systems analysis. Forecasting is needed in every systems analysis. Before any proposed action can be evaluated, we require a forecast of the future "state of the world," or context in which the action of some sort is to be taken. Forecasting is indicated even when we just want to discover if action is needed. Weather forecasting is one example, econometric forecasts used to draw inferences about the future state of national economies are another. We should note that, although sophisticated models and extensive statistical data analyses are used in these two forecasts, we do not insist on knowing the cause-effect relations. The forecasting models show *correlations*, but may fail to show *dependencies*. It is a common pitfall to neglect the difference, and thus to draw false conclusions about what a deliberate action may bring about. For example, we cannot cause rainfall by forcing the birds to fly at low altitudes, although the two facts are known to be strongly correlated in some climates (because both of them are effects of the same cause–air humidity).

A forecast of the future state of the world is, of course, needed in order to predict the consequences of an alternative, because these consequences depend on both the properties of the alternative and the context in which it is implemented. If our confidence in the accuracy of the forecast is not extremely high, the usual case, we will want to carry out the analysis for several different projections of possible states of the world.

Forecasting techniques. Forecasting future states of the world can be done in a variety of ways. Techniques range from "scenario writing" (i.e., preparing a set of assumptions about the future state of the world generated by tracing out a hypothetical chain of events) to mathematical forecasting models. Whatever technique is used, a forecast is always based on past and current data, observations, or measurements. When expert judgment alone is employed, it is carried out to a large extent implicitly. Systems analysis forecasting is based on quantitative models supplemented by scenario writing.

It may be appropriate, at this point, to indicate that even the best forecasting technique determines the future only in a probabilistic way. For example, it may—in the best case—state the expected value and the variance, or the confidence interval within which the value will be contained with some probability. The variance, or the confidence interval just mentioned, is bound to increase as the future considered is more distant. A forecasting technique should be chosen that is not too sophisticated for the available data. If data are scarce or inaccurate, simple judgmental forecasting models are often as good as the very complex ones. It may be impractical, in the early stages of analysis when more qualitative answers are sought, to attempt to use the more complex forecasting models.

In some applications of systems analysis it is appropriate to replace a probabilistic forecast of the future or an impartial scenario by an active element, an element that will respond to our actions in such a way as to purposely upset the potential benefits.

For example, when a plan for developing water resources is being considered, we may ask whether the water demands of all users will be satisfied under all possible circumstances if this plan is implemented. This question calls for an examination of the worst case of the weather and other conditions. We can, for that purpose, treat the state of nature as acting against us. In the model, we can assign the role of nature to an antagonistic player, and thus make use of *gaming*. Needless to say, to get reasonable conclusions, the action possibilities available to the opponent will have to be bounded in some way; otherwise, no water system could withstand the test. In any case, the game may reveal what exogenous conditions are the most dangerous, and we can then try to assess whether these conditions are likely to happen.

In many analyses there is a need to consider infrequent contingencies, events or conditions that may happen whose probabilities are low or very low, but which—if they happen—have significant consequences. Usually, these consequences are of a detrimental nature—if they were benefits we would not worry.

6. DETERMINING THE CONSEQUENCES

The future and uncertainty. An important analytic task is to predict the consequences (also referred to as impacts, effects, or outcomes) of each alternative that is being considered. As this prediction depends on the context or state of the world before and during the period in which the alternative is implemented, the results are uncertain. To get an idea of the nature of this uncertainty, the predictions are usually made for several alternative futures.

Given a particular forecast or assumption about the future of the world, assessing a course of action involves answering two questions:

(i) What will happen as a result of this action?

(ii) What will happen without this action?

Neither of these questions can ever be answered with certainty, because both still involve one or more forecasts of future conditions, i.e., of the future states of the world, or at least the segment of the world being considered in the study.

A particular alternative will have a large number of consequences. Some of these are *benefits*, things that one would like to have and which contribute positively to attaining the objectives; others are *costs*, negative values, things that one would like to avoid or minimize. Some of the consequences associated with an alternative, although they may have so little apparent effect, positive or negative, on attaining the desired objective that they are not considered in the evaluation, nevertheless may significantly affect or spill over on the interests of other groups of people or other decisionmakers. These, in turn, may be able to affect the decision through pressure on the decisionmaker or by making their objections known during the process of implementation. It may therefore become necessary in the course the study to enlarge it by introducing these effects or spillovers into the comparison of alternatives.

In the broad sense, costs are the opportunities foregone—all the things we cannot have or do once we have chosen a particular alternative. Many, but by no means all, costs can be expressed adequately in money or other quantitative terms. Others cannot. For example, if the goal of a decision is to lower automobile traffic fatalities, the delays imposed on motorists by schemes that force a lower speed in a relatively uncrowded and safe section of road will be considered a cost by most drivers. Such delay not only has a negative value in itself, which may be expressed partially in monetary terms, but it may cause irritation and speeding elsewhere and thus lead to an increased accident rate or even to a contempt for law, a chain of negative consequences difficult to quantify.

An important question, and one of the analyst's important decisions, is to determine which consequences to consider. Which are the relevant ones? We cannot avoid some assessment of the magnitudes and values of the consequences at an early stage. For practical reasons, analysis must be limited: if we consider too many phenomena in the physical, economic, and social environment as being related to the issue under investigation (too many impacts), then the analysis will become expensive, time-consuming, and ineffective. The important consequences are those the decisionmaker will take into account in making his decision, but his list may have to be amplified, for he is an interested party and may stress beneficial outcomes while neglecting those implying costs irrelevant to him but detrimental to others.

Therefore, the major responsibility is with the analyst: what consequences to consider is one of the important secondary decisions in the study. There is little, if any, theory on which to base this decision. Initial assessments based on experience, common sense, and understanding of the issue are a starting point, but may have to be revised in the course of analysis.

There is one more question related to listing the relevant consequences. How far ahead into the future shall the consequences be considered?

At least three factors influence the answer:

- first, how far-reaching are the objectives (what is the decisionmaker's time horizon)?,

- second, how long will the consequences (beneficial and detrimental) last? and

- third, how important is the future regarded in comparison with the present (what is the discount rate)?

These first two factors are quite different, and they may be conflicting in the sense that an action taken to achieve a short-term objective may have long-lasting consequences that make it harder to achieve an objective more remote in time. The time horizon of analysis has to be matched to both; the analyst is obliged to tell a short-sighted decisionmaker what the consequences of his action will be in the more distant future.

The third factor may be overriding; if we are not concerned about the future (if our discount rate is high), then it is of little significance how long the consequences extend.

Predictive models. The consequences of future action cannot be measured or observed; they must be predicted or estimated from our present understanding of the future situation and of what the real relations are between the contemplated action and its consequences.

While models of many sorts may be used for prediction, the models most used, and often the only type even considered for this purpose by analysts, are mathematical models, frequently in the form of a computer program. A mathematical model consists of a set of equations and other formal relations that attempt to represent the processes and circumstances that determine the outcome of alternative actions. These models, as do any models, depend for their validity on the quality of the scientific information they represent. Our current capability to design mathematical models in whose predictions we have confidence is limited, at least for questions of public policy, where social and political considerations tend to dominate. Here, what are often regarded as less satisfactory judgmental models, that depend more, and more directly, on expertise and intuition and are not as precise and manageable, may have to be used.

It is convenient, in these models, to distinguish two sets of factors that influence the consequences y simultaneously: the action a and the state of the world e. "The state of the world" is a name given to the set of all exogenous factors, that is, ones beyond control by action a, but which nevertheless influence the consequences y. The important convenience of this approach is that the forecast of the future conditions, and therefore most of the uncertainty, is now contained in the independent, partially random, value of e. We can write

$$y = f(a,e), \tag{1}$$

where we mean that y depends on both a and e.

The relation (1) may be considered the general form of a *predictive model*. It is "predictive" in the sense that, given a and e, it determines y. We do not imply, by any means, that (1) has some particular form, e.g., that it is a formal mathematical model. It may be a "mental model," contained in an expert's mind, never written down in any form, that nevertheless can supply statements of the sort: "if action a is taken, given condition e, y will result."

The object system and its environment. We take a pragmatic approach to predictive modeling. Rather than assuming that everything is related to, and influences, everything else, we draw a boundary between what has an influence on the consequences that we consider, and what has none (not all the outside world is considered to be the environment), and we draw another boundary between what we influence by an action (the consequences), and what we do not influence. The actual decision as to where to set these boundaries is made tentatively when the problem is first formulated, then revised, possibly several times, first when a crude model is designed to screen the alternatives, next when more refined models are designed to predict the consequences more precisely, and subsequently on iteration.

Limitations on predictive modeling; experiments. Even in the situations where the phenomena and relations required for prediction are quantifiable, the correctness (validity) of the models used for prediction is limited by many factors: restricted knowledge of the laws of system behavior, inadequate data, inability to deal effectively with very complex relations, and so on.

Some of the difficulties are:

- the data from passive observations alone may not reveal the cause-effect relations,
- the causal laws that we know, even for physical systems such as chemical reactors, are not enough alone to provide exact models because of the complexity of real systems.

If their predictive models appear inadequate, the model builders may suggest *experiments*. An experiment might consist, for example, of testing a proposed course of action on a sample, and on a parallel control group, observing the results, and then using them for arriving at conclusions about the action, or for building a model and modifying the action before it is applied full-scale (Riecken 1974).

An experiment can tell how the system reacts in the present, but not how it will react in the future, under changed conditions that cannot be duplicated in the experiment. Because of this and other limitations of experiments, we should recognize that experimentation alone can hardly be a substitute for predictive modeling, but should be considered a supplementary activity.

Another difficulty in predictive modeling arises when the system being modeled contains one or more decisionmakers whose decisions influence the outcome. Their behavior has to be incorporated into the model. To do this individual "players" may be inserted into the model to represent something like a manager, a legislative body, a political party, or some element of society or even a sector of the economy, that in our present state of knowledge cannot be modeled satisfactorily by a set of equations or a computer program. The player is then supposed to act like his real life conterpart would act. Such human activity is often called role playing and the model a man-machine simulation.

Models of this kind, although not necessarily involving computers, have been known for a long time under the names of operational games, war games, business games, etc., depending on the context.

No model can be fully validated; that is, it can never be proved that its output will conform to reality. We can, however, increase our confidence in its predictions by working with the model, checking it against other models and against historical data, but best is to subject the model to a range of tests and comparisons designed to reveal where it fails. Such tests do not eliminate all uncertainty, but they do give the user an understanding of the extent and limits of the model's predictive capabilities.

Using models. Using a predictive model is in principle very simple: we take the proposed action as an input to it, the assumed or predicted future state of nature as another input, and work out the output, that is, the model-predicted consequences.

It is important to test the model for *sensitivity:* how much are the consequences changed if one modifies the parameters of the model and how much are the consequences changed if the exogenous factors are changed (sensitivity to environmental conditions). Sensitivity testing helps to make explicit the types and degrees of uncertainty that exist in the model outcome and to identify the dominant and controlling parameters. A similar investigation, but with respect to major changes in the assumptions about the future state of the world, is sometimes referred to as contingency analysis. See also Chapter 7.

The actual techniques by which the consequences, for given inputs, are predicted depends on the kind of model, for example, whether it is an analytic model (an explicit mathematical relation or formula) or a judgmental (mental) model. However, all kinds of useful models should permit assessing sensitivities.

We are well aware that the future can be determined only in a probabilistic way. It is therefore correct, at least in principle, to ask the model to predict the probabilistic features of the consequences. We may, for example, be interested in the range or interval within which a consequence will be contained with some given (and high) probability. Obtaining answers of this kind requires much information, which will seldom be found in systems analysis applications. In particular, adequate probabilistic data on the future state of nature, i.e., on future environmental inputs, would have to be available, but seldom are.

We should also mention that the techniques of estimating the probabilistic features of the outcomes may be quite complex and time-consuming. Unless an analytic model is available, a *stochastic computer simulation* can be carried out. In this technique, the computer model is subjected to a large number of suitably generated random inputs, which imitate the stochastic environment. A statistical analysis of the outputs provides the required probabilistic data. This kind of analysis is important in some applications. In many cases, however, a computer simulation is the least desirable model. It is costly, except in the model-building stage, and it has low insight, since it does not show how the observed outcomes are obtained. Nevertheless, it may be the only choice open (see Chapter 7 and Majone and Quade 1979).

In most applications of systems analysis, the scarcity of data and the inaccuracy of models do not permit or justify a precise probabilistic analysis. We should, however, always realize the probabilistic character of the problem and proceed cautiously. A common pitfall, for example, is to take the expected value of the environmental input as a basis for determining the expected value of the outcome. A simple example will explain what happens. Assume a crop increases with humidity, but is more sensitive to drought than to above-average rainfall. Then, calculating the average crop on the basis of average rainfall is wrong, because the losses due to dry years will be more than the gains in the wet years. In more precise terms, what we should do is to calculate the average value of y in equation (1). It cannot be obtained by putting the average value of e into the formula, unless the relation is linear.

Summary remarks. Let us come back to the main questions addressed at the beginning of this section:

- What will the future of the world be if the action is taken?
- How certain is the answer that analysis can supply?

In many worthwhile applications of systems analysis, in spite of all the efforts that can be put into model-building and forecasting activities, we usually cannot claim that the consequences we predict will happen with reasonably high probabilities. It should be understood from what has been said that this uncertainty in the answer cannot be entirely overcome. Is it, then, reasonable to spend money and time on systems analysis, to build and use models in cases where they cannot predict accurately?

The answer is yes. For one thing, the decisionmaker has to make a decision anyway, and even imperfect assistance by analysis may be better than pure judgment and intuition. Second, analysis may permit comparing alternatives, even if the absolute accuracy of predicting the consequences is low.

For example, assume there is no probabilistic forecast of the future, but only a few scenarios. If we then detect, by a consistent model-based analysis, that the consequences of action a_1 are better than those of action a_2 under all, or most, of the representative scenarios, this result is a useful indication.

Other useful indications that a model can provide are indications of sensitivity: a course of action that makes a system insensitive to exogenous factors, or makes it resilient, that is, able to recover from shocks, is a preferable one, even if we do not know its consequences exactly.

7. COMPARING AND RANKING ALTERNATIVES

Difficulties of ranking. Assume the alternatives have been selected and screened, and the presumed consequences of each determined. How can we compare them? An obvious method is to display the alternatives in a suitable framework so that the differences and similarities stand out. The analyst may also do more; for example, he may rank the alternatives according to one or more specified criteria, so that the decisionmaker's choice is made easier.

There are several reasons why ranking alternatives can be difficult:

— In most practical cases alternative A may be superior to B in some aspects and inferior in the others.

— The diverse consequences of an alternative cannot be aggregated into a single performance index that bears a satisfactory relation to attaining the objectives.

— When outcomes are spread over time, the rankings may change with time.

— There may exist consequences that are nonquantifiable on a generally accepted basis and that may be quantified by judgment only.

— The future conditions under which the proposed alternatives will have to function are uncertain. At the same time, the range of probable future conditions is wide and bears strongly on the presumed consequences.

Nevertheless, in spite of the difficulties and all the incommensurability of various effects and consequences of the alternatives, a choice has to be made by the decisionmaker.

We are concerned about the extent to which this decision can be assisted by the analyst, for example, the extent and the means by which we can reduce the variety of features of each alternative into possibly few, but nevertheless reliable, indicators.

A danger is oversimplification, i.e., of trying to merge too many things into a single index value. One should not neglect the fact that a subjective judgement by the decisionmaker on a set of displayed impacts may be more adequate than an index arrived at by arbitrary quantification, questionable arguments, and value estimates by the analysts. Simple judgement may quite often lead to the right decision, as opposed to an index-based decision, even though the index may have been correctly determined on the basis of the information available for the analyst. There is, however, a lot of significant research devoted to the problem of analyzing and modeling value systems. The study of ways of protecting the Oosterschelde estuary from flooding (described in Chapters 1 and 3) is an example in which the analysts wisely avoided any temptation to combine impacts into simple indices.

Judgmental comparison and ranking. The simplest method, as mentioned above, is to display the impacts of the alternatives to the decisionmaker. Such a display is sometimes referred to as a scorecard (see the Oosterschelde example in Chapter 3). A scorecard aims to present the decisionmaker with the full spectrum of consequences, both good and bad, and, where appropriate, with an indication of who gets a benefit and who pays the cost. The decisionmaker can superimpose on this relatively objective information his feelings for the values, as well as incorporate the value judgments of the society he represents. This approach makes it also possible to show sensitivities, that is, to show how the impacts change when parameters and external conditions vary. One merely prepares a scorecard for the same alternatives under the changed conditions, and compares it with the previous one.

The scorecard is also effective for multiple decisionmakers, for each individual may form his own opinion based on his preferences and prejudices and a consensus can then be worked out through committee action. It is also easily understood by the public at large.

Any evaluation and ranking of the alternatives by analysts or experts may ignore important factors known to the decisionmaker but never made explicit to the analysts and experts. Therefore, such ranking may be unsatisfactory to the decisionmaker. For this reason alone, he should always be presented with the major alternatives and their impacts. In other words, when we present a decisionmaker with the result of someone else's evaluation, we should produce the scorecard for all highly ranked alternatives.

The sheer mass of information, however, makes the use of indices of various sorts attractive.

Cost-effectiveness and cost-benefit criteria. For the purpose of comparing and ranking alternatives, one often tries to describe their relative merits by means of one, or at most a few, indicators (index value, figure of merit, or objective function). Any such approach has to sacrifice the details, the individual features of the alternatives, for the sake of making comparison easier.

Cost-effectiveness can be used to rank alternatives when there is a single dominant objective and the effectiveness of the various alternatives in attaining this objective can be measured on a single scale that is directly related to the objective, or is a good proxy for it. Alternatives are ranked either in terms of decreasing effectiveness for equal cost or, less frequently, in terms of increasing cost for equal effectiveness. Sometimes the ratio of cost to effectiveness is used, but this practice is open to all the objections that apply to the use of ratios as criteria, for example, because this kind of criterion masks the differences in scale (Hitch and McKean 1960).

The cost-effectiveness criterion is open to a number of objections. For one, even in the simplest cases, effectiveness may not measure value, which depends on the particular decisionmaker. For another, if the ranking is close, the decisionmaker may want secondary effects taken into account.

Another objection is that cost as used in cost-effectiveness reflects only the costs that are inputs—the money, resources, time, and manpower required to implement and maintain an alternative. The penalties or losses that 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 must be taken into account in other ways.

Finally, even if cost and effectiveness are properly determined, the decisionmaker is still faced with the problem of what to do. He needs both a way to rule out or accept the alternative of doing nothing and then one to set the scale of effort—either a cost he must not exceed or an effectiveness level he needs to achieve. The ratio of cost to effectiveness is not a satisfactory guide (Hitch and McKean 1960), even if he is totally uninterested in the scale of effort.

Cost-benefit analysis, the most commonly used criterion in nalysis for public decisions, can, in a theoretical sense, handle the difficulties associated with cost-effectiveness. In this approach, the costs and benefits that follow each choice of an alternative, properly associated with the times and probability of occurrence, are measured in the same units, usually monetary. The excess of the total benefits over total costs is then the criterion. Whether such a transfer into monetary or other terms can properly include all, or an adequate number, of the relevant considerations is, however, a difficult question. For a more complete discussion, see Fischhof (1977), Mishan (1971), Sugden and Williams (1978), and Chapter 8.

Value and utility approaches. If a scorecard approach is used, there will be as many scorecards for each alternative as there are scenarios of the future to be considered. On each scorecard the number of entries is the number of impacts multiplied by the number of alternatives to be evaluated and compared. The result may be that the amount of data is far too large for the decisionmaker, without some aggregation, to make a judgmental ranking and choice.

It is therefore understandable that there is a tendency to evaluate each alternative by a single indicator such as *effectiveness for fixed cost* or *net benefit* in a cost-benefit analysis. We still have, of course, the various possible futures, and hence several different values of the chosen indicator for each alternative. Nevertheless, the display of alternatives is more lucid and transparent.

The concept of using a single indicator for many noncommensurable features of an object, in our case, an assumed alternative, is well known to decision analysts, who have formalized it as a *multiattribute value function* (Keeney and Raiffa 1977; Bell, Keeney, and Raiffa 1976; Raiffa 1968). In this approach one tries to build a function by which a value v is assigned to the consequence of an alternative, whereby this consequence is assumed to have n different value-relevant attributes:

$$v = f\,(y_1, y_2, etc.), \qquad (2)$$

where y_1, y_2, *etc.* are the value-relevant attributes measured on their appropriate scales.

The function in (2) is a model of the decisionmaker's value system. It has to be established on the basis of his preferences, that is, of his individual judgments, and this is where the difficulties arise. In practice, it is, for many reasons, hard to obtain a value function that could replace the actual decision on a complex and unique issue. It is possible, however, for multiattribute value functions to be used as a guide or directive in the initial selection, design, and fine tuning of alternatives, or as one of the ranking criteria to be compared with rankings done by other means. A public official's preferences are, in general, the preferences of the people he represents; it is through this association that the analyst can get an idea of the decisionmaker's preferences. One still faces the problem of uncertainty: even if we agree to evaluate the alternatives by a single indicator for each of the possible states of nature, how should they be ranked, since we do not know which of these states of nature will occur?

Let us assume that, from one source or another, the probabilities of the various future states of nature are known or can be estimated. It seems quite natural in this case, or at least simplest, to rank the alternatives on the basis of the mathematical expectation (expected value) of the outcome.

Using the multiattribute value function expressed by equation (2), which assigns a single value indicator to a given alternative under one state of nature, one can calculate the average value for each alternative over all possible states of nature. Then, the alternatives can be ranked according to the average, i.e., expected, values.

It should be noted, however, that a straightforward average may not indicate the choice that a given decisionmaker would make.

To take account of this, we use the notion of *utility*, a basic concept used in the theory of *decision under uncertainty*. This theory assigns utilities to consequences in such a way that ranking expected utilities of alternatives is the same as the decisionmaker's preference order for the same alternatives.

Utilities are assigned to consequences by means of *utility functions;* a utility function describes the attitude of the given decisionmaker toward risk, and is thus different for risk-averse and risk-prone decisionmakers (Keeney and Raiffa 1977).

Direct use of utility theory, i.e., of utility functions and the expected utility principle, for ranking alternatives and, in particular, for a final choice, cannot be recommended without reservation. Assigning utility via utility functions involves a great deal of judgment by the analyst; several simplifying assumptions with respect to the form of these functions are also indispensable. Nevertheless, as in the case of miltiattribute value functions, expected utility may be valuable as one of the means by which the alternatives can be screened and assigned a tentative ranking, even if it cannot be recommended as a unique and ultimate criterion for choice.

Summary remarks. Relatively little can be added to what was said in the first paragraph of this section: comparing alternatives is, in all practical cases, difficult. We should also remember that, although comparison and choice go together, the two parts are done by different people. It is the duty of the analyst to provide a comparison of alternatives and possibly a ranking, but it is the right and responsibility of the decisionmaker to make the choice.

It is, therefore, reasonable not to rely entirely on the rankings provided by cost-benefit, multiattribute value functions, or utility functions. A scorecard of the alternatives, reduced, perhaps, to the most relevant attributes, should accompany any rank-ordered list of alternatives.

The analyst should not be upset if the choice of the decisionmaker is the third-ranked or fourth-ranked alternative. Such a choice indicates only that there are additional aspects and values that the decisionmaker did not disclose before, or that were misunderstood by the analyst. The analysis at this stage may be considered a success if the decisionmaker has made an analysis-based decision in the sense that he has chosen a course of action taking into account consequences that have been duly and appropriately analyzed. We must remember, however, that the analyst's goal is not merely to find the course of action best suited to achieve the decisionmaker's objectives and satisfy his constraints, but to find the course of action closest to this ideal that can be accepted by the other participants in the decisionmaking process and then implemented without undesirable modification, or extra cost and delay.

As mentioned in section 4.2 the analyst's role does not necessarily end at the choice by the decisionmakers of a particular course of action. Analysts, although sometimes not the original analysts, will be called on to assist with implementation, especially in the early part of this process when there may be a need to interpret aspects of the program, as well as for modifications due to circumstances that were impossible to anticipate earlier. Other analysts—they should not be the original analysts—will also play an important role when it comes to evaluating the results of the implemented action, and the original analysis itself.

As a final word, it cannot be too strongly emphasized that success in applied systems analysis, however it is measured, depends more on knowledge of the subject matter and the clarity of the objectives than on knowledge of its methods.

If the reader compares what has been said in this chapter with the accounts of systems analyses set forth in Chapters 1 and 3, he will see some connections--but perhaps not as many as he would have expected. The reason is a simple one: In published accounts of completed systems analyses the authors focus attention on the findings and the direct path that led to them, suppressing all of the contributing activity that does not contribute directly to the results. Thus, for the most part, one can only imagine the false starts, the approaches that did not work, the debates over objectives, the alternatives that proved to be uninteresting, the data that were inadequate, the interactions with the client in the process of developing the framework for the analysis, and so on and so on. These matters could be discussed, but only by the analysts directly involved, and the resulting length would exceed what seems reasonable for a handbook--nor would most analysts want so much washing hanging on the line.

Thus, this chapter distills from many experiences what many analysts have learned in the hope that it will help future investigators--but with the warning that everything that is said here must be reconsidered carefully in the light of the case in hand. Experience in facing such issues is an essential part of an analyst's training, but, while some of this experience can be passed on in papers, books, and this *Handbook*, much will have to be learned on the job. An apprenticeship under a wise and experienced systems analysis leader is the best way of learning the craft. Perhaps the best use of this *Handbook* for the fledgling analyst is in connection with such an experience, to provide questions, contrasting experience, and an entry to the large literature that can extend his experience.

This chapter has discussed systems analysis as though a single decisionmaker were being served--and, indeed, it began with an argument that this was an appropriate focus. On the other hand, all of the examples of systems analysis presented in Chapters 1 and 3 clearly involve more complicated administrative situations: For the simplest case--that dealing with improving blood availability and utilization--it would be fair to say that the head of the Greater New York Blood Program was the client, but this official's operations are hedged about by a very large number of administratively independent heads of hospital blood banks, all of whom had to agree to a cooperative arrangement of the sort proposed by the analysts before it could be brought into being and be effective. In fact, persuading these blood bank officials that the new cooperative system was in everyone's best interests was one of the key implementation tasks facing the analysts at the end of their analytic work.

Similarly, the Chief of the Wilmington Bureau of Fire can be considered the client for this case, but he too was enmeshed in a bureaucratic and political structure that constrained his choices, and had to be convinced of their value before they could become effective. Not the least of these influences came from the firemen's labor union. While the Netherlands Rijkswaterstaat commissioned the Rand Corporation's systems analysis work (as an extension of their own work on protecting the Oosterschelde estuary from flooding), the network of decisionmakers was very large, with the Netherlands parliament playing an ultimately deciding role.

For the IIASA study of the world's energy future there was, of course, no world decisionmaker to commission the study or to report its findings to; rather, there were thousands of persons in national governments, energy enterprises, and the general public interested in the findings, and many of these could reflect them in some way in their own activities or attitudes. However, for a government or an energy enterprise to make decisions sympathetic to the IIASA study's findings would almost invariably involve the organization making a complementary study of its own focused sharply on its own concerns. In fact, the IIASA world-wide analysis has been followed by a number of such studies.

In view of the evidence of our examples that the decisionmaking situation is almost invariably complex, can we sustain the argument at the beginning of this chapter that it is useful to begin the discussion with the presumption that there is a single decisionmaker being served by the systems analyst? We certainly cannot do so if we then try to carry this presumption into real life. However, we can accept this convention provided it is a useful device for thought and discussion--as we hope this chapter has established. It may be particularly useful if it serves to sharpen the analyst's appreciation of the complications of the actual decisionmaking situation he is facing, and forces him to think constructively and work effectively toward it. Otherwise, knowing that there is no decisionmaker for a global problem, he may fail to sharpen his findings sufficiently to make them usable to any decisionmakers with smaller purviews.

In sum, the unitary decisionmaker of this chapter stands for a class. In this chapter we have been able to think of the class as a unit, but in practice the analyst will eventually have to consider the individual members of the class to an appropriate extent. To the analysts bruised in the decision wars the class may seem a Hydra-headed monster--but it must be considered, both collectively and individually.

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