HANDBOOK OF SYSTEMS ANALYSIS

VOLUME 1. OVERVIEW

CHAPTER 6. OBJECTIVES, CONSTRAINTS, AND ALTERNATIVES

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October 1981
WP-81-142

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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 6. 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 6. OBJECTIVES, CONSTRAINTS, AND ALTERNATIVES

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To help a decisionmaker means to help him achieve his true objectives; to do so, it is crucial to discover what they are. To find feasible alternatives (i.e., ways to achieve the objectives that are not ruled out by the constraints imposed on the decisionmaker's actions by nature, circumstance, authority, or the decisionmaker himself) is the central task of systems analysis. This chapter, expanding the remarks in Chapter 4, discusses problems of clarification and measurement related to objectives, the roles of objectives and constraints in determining alternatives, and methods for discovering and improving alternatives, and eliminating the inferior ones.

1. OBJECTIVES

Ideally, problems with objectives (and with certain constraints, since they play a role somewhat similar to that of objectives) should be settled very early in a systems analysis study. In practice, however, this is seldom possible. Unfortunately, a clear, well thought through, precisely spelled out, and analytically useful statement of what the decisionmaker wants to accomplish is rarely presented to the analyst at the time the study is commissioned. Nevertheless, some idea of what is wanted is available. Tentative objectives, specific enough to get the analysis started, can be selected; these should suggest possible ways to achieve the alternatives. The impacts, or consequences, of implementing these alternatives are then imagined or estimated, and their projected implications used to reexamine the first formulation of objectives and introduce modifications. As the study progresses, the analysts, their sponsors, and others learn from this early work. The decisionmaker for whom the work is being carried out is also influenced by pressure from interested constituents and from other decisionmakers who may see their domain adversely affected by what they anticipate is likely to be done as a result of the study. Hence objectives and alternatives may change and constraints may be introduced or removed. This is one of the major reasons why systems analysis must be an iterative process.

To someone without systems analysis experience it may seem odd that we start this discussion with the implied assumption that the objectives will not be spelled out sufficiently to allow the analysis team to adopt them as given and proceed to their work. However, experience is almost universal on this point: decisionmakers seldom have carefully articulated objectives. This apparently troublesome fact—which leads to the iterative search for realistic and acceptable objectives as part of the systems analysis—may lead the wishful analyst into dreaming of the "perfect client" who is the exception, so that he can get quickly beyond the beginning statement of objectives to what he may think of as the meat of the analysis. However, here again the voice of experience suggests that it may be better not to have such clearly defined obejctives right at the beginning before at least some preliminary analysis has taken place, for the objectives stated at the beginning will probably not be as well thought through as they should be, with the result that the analyst will face the dilemma of tailoring his work to objectives he knows to be defective, or trying at the end to alter these fixtures in order to squeeze in some new perspectives. The experienced analyst does not rue the existence of hazy starting objectives; rather, he is thankful for them, as they offer him the opportunity to work with his client toward realistic and acceptable ones as the study proceeds.

The objectives of an individual or of an organization are the principles that determine how they are to act. As Sugden and Williams (1978) put it, "They are not pious incantations of ethical or ideological beliefs which unfortunately cannot be acted on because of 'political constraints'; they express intentions to act." The analyst needs something specific enough to limit the set of alternatives and to guide the choice among them. In particular, he would like this specificity to be such that he can tell the decisionmaker (as soon as he can get some clue as to what they are) what sorts of alternatives and consequences are likely to result. The decisionmaker can then confirm that the statement of objectives expresses his intentions and offer another suggestion if it does not.

Even when objectives appear to be well specified at the outset, they can seldom be adopted uncritically by the analyst. Means are sometimes taken for ends; a decisionmaker may say that his objective is to find out where to place a new comprehensive medical center in his district, but his real objective may be broader, say to improve the totality of health services in his community; better ways to achieve the real objective may be to provide several neighborhood health centers or services through other mechanisms (hospital outpatient clinics or health maintenance organizations). Perhaps programs focusing on maternal and child health services or screening apparently well people to turn up heart and cancer conditions should be considered. Unless the broader objective is investigated by the analyst, these latter alternatives will not appear and the decisionmaker may never realize how much more he could do with his resources.

Desired goals can be stated easily, but specifying objectives one has a reasonable hope of attaining may take considerable thought, even research. It may not make sense to make up one's mind as to what one wants until one has a fair idea as to what he can get. An important way analysis helps in clarifying objectives is that it determines the undesirable as well as the desirable conseqences of the alternatives that follow an assumption about objectives. The decisionmaker, when confronted with these consequences, can ask himself whether he is willing to accept what they imply. If not, he will have to modify his goals.

In the effort to clarify objectives and find ways to measure their attainment, it is helpful to discuss the issue under analysis with several people who have no stake in the outcome—critical and skeptical outsiders. One seeks answers to questions such as "What is really at stake here?" Since attainment of the ultimate goal may be many years off, what practical intermediate goals should we strive for?

For certain issues, the question of whose objectives are relevant has to be considered. For public issues, it is some subset of the citizens of today or of future generations; the decisionmaker is merely the person or organization charged with the responsibility for changing the system, and the analyst may have to find some discrete way to make this clear (Sugden and Williams 1978, pp. 232-242).

High-level objectives tend to be ambiguous, for it is a political advantage to appeal to as many people as possible. In fact, it is often much easier in the political process to agree on an action or program than on a goal (unless the latter is indefinite), for people may have different motives for what they are willing to do. High-level objectives that express general good intentions are valid over a long time period and are the easiest for the decisionmaker to state (Hovey 1968). A frequent problem is that such objectives are difficult for the analyst to formulate with sufficient specificity for direct use in analytical studies. A lower-level objective that is a means to achieve the higher-level objective may be required for analysis. To build a new health center is both a lower-level objective and a means to improve health services, a higher-level objective. Clear definitions of lower-level objectives are usually more easily provided and are technically easier to use for finding and ranking alternatives. However, misleading results may occur if the lower-level objectives are not, under all circumstances, an appropriate means to achieve the higher-level objectives. The relation need not be direct; for example, to relocate fire stations to provide better fire service, the objective of lowering the average travel time from fire station to fire serves well as a substitute for better protection of lives and property (Chapter 3 and Walker et al. 1979). Travel time is, moreover, easily measurable and can thus serve as an estimate of the extent to which the alternatives attain the objective.

Capabilities designed with one objective in mind can differ considerably from those designed with another uppermost, even though both have the same higher-level goal. This is a difficulty that can arise when one attempts to make a relatively vague higher-level objective operational by using a more specific lower-level formulation. Wohlstetter (1964) illustrates this point for the case of automobile traffic safety:

> The city fathers would like to reduce the number of violations of the law. They would also like to fine or put in the clink as many violators as they can. There are two well known alternative techniques for accomplishing these ends; one is the familiar ambush technique; the other is sometimes called the visible patrol technique. The first increases the probability of interception and arrest. The second discourages culpability. Now if our goal is to maximize the number or proportion of speeders punished, or the total of municipal revenue through fines, probably the best way to do the job is by ambush, however uneasy such a sneaky tactic makes us. If our goal, on the other hand, is a reduction in the total number of traffic accidents, say, or in the number of attempts to violate the law (even if on the whole such attempts at evasion as do take place are more likely to be successful, since the culprit is aware of the cop's presence), it may very well be that the most frequent, obvious presence of policemen capable of instantaneous retaliation against speeders would encourage caution, and so achieve such goals best.

It is interesting to review the cases discussed in Chapter 3 in the light of these remarks about objectives:

• The basic objective of the Greater New York Blood Program is to have blood available when and where needed—always. The only admissible exception is that elective uses can possibly, when necessary, be postponed, although the costs of such decisions are recognized as making them undesirable. Deriving from this basic objective—which was being met adequately when the systems analysis was undertaken—are two subordinate objectives: to reduce the amount of blood being outdated (and hence discarded) to the lowest level consistent with the basic objective, and to reduce the costs of maintaining the blood supply at the points of use as much as possible consistent with the basic objective. The simplicity and clarity of these objectives contributed a great deal to the crisp clarity of the analysis and the success of its implementation, because these objectives were widely accepted.

• The basic objective of the Wilmington Bureau of Fire is that of any fire department: to hold down as much as possible the human (death and injury) and property losses from fire. However, owing to the lack of information in the fire-fighting community about the relations between this objective and fire-fighting deployments and activities, this Bureau—and the systems analysts called in to help with its planning problem—accepted three objectives that were proxies for the basic objective: to keep travel times to individual locations down to an acceptably low level, to keep the average travel time in a region at an acceptable level, and to maintain reasonable workloads for fire companies. As in the case of the Greater New York Blood Program, before the systems analysis began the Wilmington fire fighters were achieving their basic objective to a level acceptable to the community, so that one could argue pragmatically that the existing level met the basic objective, and the words "acceptable" and "reasonable" in the statement of the proxy objectives imply that fire-fighting officials will exercise judgments based on the craft skills that they have learned from many years of experience. Thus, the objective of the analysis could be to achieve a redeployment pattern maintaining the level of achievement of the basic objective, possibly achieving economies, or raising the standard of service as judged by the proxy objectives.

• In the case of the study of the Oosterschelde estuary, the basic objective was to protect it from future flooding caused by violent storms, but the level of protection to be provided, as well as the myriad other objectives (ranging from the concerns about microscopic organisms to those of humans) were all open for analysis. While the basic objective was widely agreed to, the analysts could count on no such consensus for the others, and, in fact, had to keep them all flexibly in view, in order to allow the many parties of concern to make their own judgments about them.

• In the case of the IIASA study of the world's energy future for the next fifty years, since there was no world energy executive—or even a closely knit set of officials who could be thought of as an approximation—the analysts had to attribute objectives to the world that would seem reasonable to the many executives and analysts who might later want to use the study's findings as a contribution to their own thinking about their narrower problems. In broad terms the basic objective assumed by the analysts was that the world would want to sustain its use of energy indefinitely at a level that would maintain the standard of living in developed parts of the world and allow the developing parts to increase their standard, while accepting the population growth that is expected. Supporting this basic objective there were many other objectives—for example, making the world's energy future grow by a natural and fairly smooth evolution from the present world energy posture. While most of these supporting objectives were expected to be widely subscribed to, variant views were expected on many—an expectation that proved to be realistic. For example, some solar energy enthusiasts feel that the assumption of a sustained standard of living is inappropriate, that a smooth transition should be replaced by a sudden switch to solar energy, and that future world energy use should be assumed to undergo a significant per capita reduction.

In sum, it is important to consider and evolve a clear concept of the objectives, and to seek as much of a consensus on them as possible. However, our examples suggest that the consensus may not be achievable, particularly at the beginning of the analysis, when the consequences of various objectives may not be perceived realistically by all concerned. On the other hand, when there are myriad objectives, many conflicting–as in the Oosterschelde analysis–the work can illuminate them and their consequences so as to allow accommodation among potentially conflicting parties in the process of deciding on a course of action. All of these matters emphasize the importance of having a clear view of objectives, all of them that are relevant, even if they cannot be rationalized into a congenial set.

In brief, finding the right objective is crucial, more important than it is to find the very best alternative. The wrong objective means the research is devoted to the wrong problem; to designate a slightly inferior alternative is not nearly so serious.

Measuring effectiveness. To be considered an alternative, a course of action must be consistent with the decisionmaker's objectives, i.e., offer some hope of attaining the objectives, or at least of bringing them closer. For the purpose of quantitative analysis we would like a scale on which the effectivenesses of the various alternatives in attaining the objectives can be measured. The alternatives can then be compared and ranked in terms of effectiveness, that is, by their standings on the effectiveness scale.

Unfortunately, a satisfactory scale cannot always be found easily. The problem is that many objectives are difficult or impossible to quantify directly in any useful fashion. It is therefore necessary to use a surrogate or proxy, a substitute objective that can be measured and that approximates the extent to which the real objective is attained. The problem is to get a good approximation. Thus, to measure the quality of medical care in a community, the infant mortality rate is often used as a proxy, even though it merely measures one aspect of the quality of medical care; to measure fire-department performance, response time is often used (Walker et al. 1979, p. 81).

One technique for finding quantifiable ways to measure effectiveness is to try several successive modifications of tentative possibilities for stating the objective to see whether any substitutes or proxies are suggested. Sometimes it can be easier to examine several possible proxies to see whether, if they were attained, the desired end would also be achieved.

The mark of a good proxy is that its achievement closely reflects achieving the real objective. Unfortunately, there are a number of inadequate but common approaches in use.

One is to use input to measure output; to compare the quality of primary school education in various districts in terms of expenditures per pupil. A second is to use workload measures or efficiency measures to compare quality of output, say, to compare the quality of primary education on the basis of teacher-pupil ratios.

Consider a single unambiguous objective, say, to improve garbage collection. To facilitate comparisons, it is useful to have a scale on which to measure the effectiveness of the various possibilities. But there is no obvious scale to measure better garbage collection, so we need a proxy—a substitute objective measured by, say, the percentage of city blocks remaining without health hazards, or the reduction in the number of fires involving uncollected solid waste, or rodent bites, or valid citizen complaints. All of these, unfortunately, treat just an aspect, not the full value, of better garbage collection. In practice, people often use even less satisfactory scales, for instance, an input measure—expenditure per household—or an efficiency measure—number of tons collected per man-hour—or a workload measure—tons of waste collected—that indicate nothing about the quality of the work.

When several attributes need to be considered, a combination is sometimes used in which the various attributes are assigned weights, resulting in an ordinal or cardinal utility function. The failing here is that the function is to a large extent the product of the analyst's judgment as to the relative importance of the attributes and not that of the responsible decisionmakers. The decisionmakers, if they were willing to spend the time, could work out their own set of weights (with guidance from the analyst) but even here the analyst's influence is powerful. Hatry (1970) comments:

> There is no doubt that the job of decisionmakers would be easier if a single effectiveness measure could approximately be used. However, I contend that such procedures place the analyst in the position of making a considerable number of value judgments that rightfully should be made in the *political* decision-making process, and *not* by the analyst. Such value judgments are buried in the procedures used by the analysts and are seldom revealed to, or understood by, the decision makers.
>
> Such hocus pocus in the long run tends to discredit analysis and distract significantly from what should be its principal role: to present to decision makers alternative ways of achieving objectives, and to estimate and display all the major tradeoffs of cost and effectiveness that exist among these alternatives. [Emphasis in the original.]

The Oosterschelde analysis described in Chapter 3 shows, not only that it is not necessary to push disparate measures of effectiveness into a common measure, but also displaying them with their relevant objectives can have important values for the decisionmakers.

In selecting a scheme to measure effectiveness, we are not only looking for a scale that is positively correlated with the objective under consideration but also for one for which the required data can be obtained.

Suppose, for example, an ongoing government program for training computer operators is to be evaluated. If the objective of the program is the eventual increase in the gross domestic product (GDP), how can effectiveness be measured? One possibility is to calculate the increase in GDP caused by the increase in the income of the trainee that results from the training he receives; this requires that the income of the trainee be total compensation (i.e., include fringe benefits) and that adjustment be made for displacing previous workers, if any, by the trainees.

But how do we actually get the needed information? By following the history of the trainees after they leave the program, it is possible to estimate their actual income, but how much of any change can be attributed to the training? One way to get the desired information would be to carry out a social experiment (Chapter 7) in which participants are assigned randomly either to the program or to a control group, and then follow the wage experience of both groups. But the experiment could well be much more costly than the training program alone. A practical substitute would be to use the wage experience of a group of people having similar backgrounds to the trainees for comparison purposes. It is imperfect, but conceptually correct; a measure based on it is likely to be superior to an output measure such as the percentage of trainees to get jobs as computer operators.

Multiple objectives. A decisionmaker may have more than one objective. If so, they may conflict; he may wish to reduce expenses but increase staff or to increase highway safety on a motorway between two cities but to decrease the travel time. In any event, if there are two or more objectives, they compete (except possibly for pairs where one is the means to the other) in the sense that, for given resources, if the decisionmaker strives for maximum attainment of a particular one, he must accept less than maximum attainment of the others.

As is obvious, one cannot maximize benefits and minimize cost simultaneously or do something similar for any other pair of goals. But if the measures of attainment for these goals have a common unit, one can create a new goal to achieve the most advantageous combination. For instance, one can maximize benefits minus costs (as in cost-benefit analysis) provided both can be expressed in monetary units (Nagel and Neef 1979).

If there are several decisionmakers, each with his own set of objectives, a number of different approaches can be used to expedite the process of reducing the number of objectives to something that can be used as a basis for analysis (Eilon 1972, Keeney and Raiffa 1976). The following list gives some examples—each of these approaches requires discussion among the decisionmakers holding competing objectives and a certain amount of compromise and concession:

- Objectives that are only means to achieve other objectives can be eliminated.

- If all the objectives can be interpreted as means to achieve some higher-level objective, and a relevant way to measure its effectiveness or that of a good proxy corresponding to this objective can be found, then this higher-level objective may serve as the single objective.

- A preference ordering of objectives can sometimes be set up and used to effect tradeoffs among them. A solution is first determined using the highest-ranking objective; then an effort is made to achieve as much of the second as possible without sacrificing too much of the first; and so on.

- All objectives except (the most important) one can be converted into constraints, by agreement on a minimum level of attainment acceptable on each.

- Tradeoffs among the objectives can be worked out and used to construct a composite index of worth, a value or utility function (decision analysis; see Raiffa 1968).

- No effort can be made to "optimize" with respect to any specific objective. Instead, all objectives can be converted into constraints and a solution determined under the agreement that any solution satisfying all constraints—called a *satisficing* solution—will be "good enough."

It is, of course, not always possible to reach the agreement necessary to implement any of these simplifications, although the use of special techniques to increase the *value sensitivity* of decisionmakers (Dror 1975, p. 250) may make them more amenable to compromise. We will treat value sensitivity in a section under that title in Chapter 8 after discussing satisficing and the more common schemes for presenting results: cost-effectiveness and cost-benefit analysis, decision analysis, and the so-called "scorecards."

What we cannot do satisfactorily is construct a unique group objective from all the individual objectives that automatically weights all the separate ones. Arrow (1951) has proved, for example, that, under a few reasonable assumptions, there is no general procedure for obtaining a group ranking from the rankings of the individual group members.

Some idea of the interplay among objectives and their measures can be gained from looking more closely at the blood availability and utilization example. The basic objective is, as we said earlier, to have blood available when and where needed. However, to this baldly idealistic objective—which could well entail very high costs—was added a qualification: that elective uses of blood be allowed to be postponed when supplies are short. Within the framework of a system meeting this goal, the analysts considered two additional objectives: to reduce the amount of blood being outdated (and hence discarded) and to reduce the costs of maintaining the blood supply at the points of use (the proxy measure for this objective being the average number of weekly deliveries to a hospital blood bank).

The basic objective could be achieved by maintaining very large supplies at the hospital blood banks at all times, but this policy would entail very large outdating rates; in fact, most areas in the United States were pursuing policies dominated by this sort of approach and were experiencing outdating rates of 0.20—that is, a fifth of the blood donated was not put to its ultimate good use. On the other hand, very low outdating rates could be achieved merely by keeping minimal stocks at the hospital blood banks—but this would run the risk of prejudicing seriously the basic objective of availability where needed whenever needed. Another policy could possibly meet the demands of the basic objective and the desire to reduce outdating to a minimum: keep all blood centrally and deliver expeditiously when needed. Very little speculation is needed to determine the unacceptability of this policy; in addition to escalating delivery costs, there would be unacceptable time delays in the face of short-term health emergencies.

The study then was aimed at a compromise among all of these objectives, and achieved it by keeping the basic objective at its former high and acceptable level while reducing the outdating and shortage rates (these latter causing extra deliveries to be made from the center to the hospital blood banks). The results of the first test were: outdating reduced from 20 percent to 4 percent, average weekly deliveries per hospital blood bank reduced from 7.8 to 4.2 (these figures also being an indication of the increased adequacy of the hospital blood bank's supply, especially since 1.4 of the 4.2 weekly deliveries were to cover shortages, the other 2.8 being routine prescheduled deliveries). Some experimentation with their models convinced the analysts that the 4 percent outdate rate was about the smallest that could be achieved in this balance among the three objectives; in other words, this outdate rate represented a cost of pursuing a balance, rather than just this one objective.

Similar discussions could be generated for the other examples in Chapter 3, but they would of necessity be much longer—too long for the space available here. Nor would they contribute essentially new insights. However, the diligent reader would find the sources from which we have drawn our brief accounts a rich mine of instructive issues of the sort indicated in the blood-bank discussion.

2. CONSTRAINTS

The objectives suggest the alternatives, the constraints restrict them and reduce the number of possibilities that can be considered. Constraints are thus more likely to simplify than to complicate the work of the analyst.

Constraints often have a function similar to objectives from an evaluation point of view. Herbert Simon (1964, p. 20) writes:

> It is doubtful whether decisions are generally directed towards a goal. It is easier and clearer to view decisions as being concerned with discovering courses of action that satisfy a whole set of constraints. It is this set, and not any one of its members, that is most accurately viewed as the goal of the action. If we select any of the constraints for

special attention, it is (a) because of its relation to the motivations of the decisionmaker, or (b) because of its relation to the search process that is generating or designing particular courses of action. Those constraints that motivate the decisionmaker and those that guide his search for actions are sometimes regarded as more "goal-like" than those that limit the actions he may consider, or those that are used to test whether a potential course of action he has designed is satisfactory. Whether we treat all the constraints symmetrically or refer to some asymmetrically, as goals, is largely a matter of linguistic or analytic convenience.

When a distinction between objectives and constraints is made, it is usually based on the idea of a constraint as an absolute restriction, in contrast to an objective or goal that may be open ended. Majone (1978) suggests, and we concur, that when there are several objectives they can always be traded off at the margin if this leads to an improvement in the total utility. That is, it is reasonable to sacrifice a particular objective if the situation on the whole is thereby improved. A constraint on the other hand, cannot be so exchanged against other constraints, for its logical force resides wholly in its inviolability. Thus, the translations of a decisionmaker's desires into a problem formulation, including the definitions of limit values (constraints), must be done with a lot of care. For once a constraint, a limit value, is established by, or in concurrence with, the decisionmaker, it will be held to during analysis (although, of course, it may be changed in a later analysis). Majone (1978) remarks:

> The opportunity cost of a proposed policy constraint must be carefully considered before the constraint becomes firmly embedded in the analytic structure. As Hitch and McKean (1960, p. 196) write, 'casually selected or arbitrary constraints can easily increase system cost or degrade system performance manifold, and lead to solutions that would be unacceptable to the person who set the constraints in the first place.' They cite the example of a weapon-systems study, where a

constraint on acceptable casualities led to solutions in which 100 million dollars was being spent, at the margin, to save a single life. Many more lives could have been saved with the same resources. Had the policymakers realized the opportunity cost of their safety requirements, they would probably have set them at a lower level. Or, like good utilitarians, they may have chosen to treat the risk factor as a subgoal, to be optimized compatibly with other system's requirements and the available resources.

The constraints may be so restrictive that no alternative will attain the objective. Demonstrating that something cannot be done or can only be done if certain constraints are removed may be just as important as showing that something can be done, for it can save a great deal of wasted effort and be on a sounder basis.

Here again the blood availability example illustrates the points. We have so far treated the desirability of always having blood available when and where needed as an objective, because the existing system allowed modest shortfalls affecting elective procedures. However, if it had been considered and treated as an inviolable constraint—one that could easily be advocated by someone not familiar with the usual working of the health system—the analysis and its results would have been violently transformed, as also would its results.

On the other hand, a constraint may be intrinsically inviolable. For example, the IIASA energy study could not yield a use of fossil fuels over the next fifty years greater than the available supply. However, careful scrutiny of the technical possibilities yielded new views of this constraint, as new forms of fossil resources could be exploited as fuels when technology and economics become favorable (example: oil from oil shales) or the available supplies could be extended by combining them with more advanced technologies (example: using breeder reactors to fuel coal gasification).

The lesson is simple: objectives and constraints must not be treated as sacredly inviolable, but must be scrutinized from many points of view as the analysis proceeds and technical possibilities emerge—and their roles should be subject to change.

3. ALTERNATIVES

The search for alternatives is the activity that gives form and structure to systems analysis. No amount of modeling and evaluation will help to move the effort toward a solution unless the analyst can discover, design, or invent one or more satisfactory alternatives, that is to say, actions or policies that offer hope of accomplishing what the decisionmaker wants. No amount of evaluation will uncover the best alternative available unless it appears among those investigated.

An obvious illustration is suggested by Sugden and Williams (1978, p. 231):

> Consider, for example, a cost-benefit analysis that compares the effects of undertaking a large programme of road-building in a city with the effects of taking no action and which finds that the former policy is to be preferred. This might then be used as an argument that the whole programme ought to be undertaken even though all that has been shown is that this is better than doing nothing at all. It might well be that undertaking only a part of the programme is preferable to either of the alternatives that has been studied.

To generate alternatives at the start of a study is clearly a creative act. Once we have one, it is easy to design an infinity of related alternatives that are more costly or less efficient or possibly even marginally better, but significant improvement is harder to achieve. One must make a deliberate effort to think of possibilities; here brainstorming and talking to a variety of people helps.

To design alternatives frequently means becoming well acquainted with the relevant technologies and working closely with the technologists with detailed knowledge of the technical possibilities. For example, the flood-control engineers developed the options for protecting the Oosterschelde estuary that were considered by the Rand team of systems analysts. In the IIASA study of world energy supply and demand a great deal of effort was expended on detailed inquiries into the possible technical options that might be available for use with many forms of energy sources: coal, oil, solar, ocean thermal, water power, and so on. The characteristic properties of these technical options could then enter the systems analysis calculations in the forms of contributions to the total energy supply, costs, material requirements, demands on the available stock of capital, and so on.

This is not to say that the systems analyst should just consult a few technologists and then adopt some alternatives. Experience shows that an interplay between the original alternatives and the issues in the analysis may suggest important options with much improved properties in the light of the compromises and tradeoffs that the analysis reveals. For example, although the IIASA study of world energy supply and demand started with the presumption that it would be possible for the world to move in 50 years from a major dependence on exhaustible sources of energy to principal reliance on renewable sources, the analysis showed that this would be so difficult as to be virtually impossible in so short a period. In fact, the study projected a significant increase in the use of energy from exhaustible sources (as Table 3.6 shows), although the proportion of the total supply from such sources could be expected to decrease somewhat (as Figure 3.10 shows). To make matters worse, the analysts were forced to project a continuing high use of gas and easily transportable liquid fuels. With use of oil and gas from fossil sources having to decline for both supply and cost-of-production reasons, these findings turned attention, as Figure 3.10 shows, to coal liquefaction and gasification, since the world has huge coal reserves.

The IIASA analysis team observed (Energy Systems Program Group 1981):

> When coal-based synthetic fuels begin to take on such a large role, the technical processes by which they are produced also become most significant. . . .
>
> In autothermal coal gasification and liquefaction schemes, both the process heat and the required hydrogen are produced by burning

coal, in addition to the amount of coal needed for the chemical carbon content of the synfuels. A large amount of energy is lost in the conversion process, and the resulting gas or liquid contains about half of the energy content of the original coal.

For the allothermal process the process heat and the required hydrogen are supplied exogenously, preferably by means of heat from a nuclear reactor such as the high temperature reactor . . . or in more futuristic schemes by means of hydrogen gas from a solar plant. The synfuels thus produced have a higher energy content than the original coal. While in both processes the combustion of coal releases carbon dioxide into the atmosphere, the allothermal process requires less coal (by a factor of 3 to 4) and accordingly releases a smaller amount of carbon dioxide than the autothermal method. . . .

Thus, in this case the analysis showed that the coal gasification and liquefaction process that made important use of other energy sources, such as a high-temperature nuclear reactor or hydrogen gas from a solar plant, offers important advantages: extending the useful life of the coal reserves, allowing the shift from readily transportable gas and liquid fuels to take place over a longer period, and reducing the amount of carbon dioxide released into the atmosphere. The detailed calculations showed this hybrid option to have important advantages when development and investment allow it to be introduced.

There are many forces that tend to restrict the range of alternatives likely to be examined. Some of the strongest are biases of various sorts due to the unconscious adherence to an organization's "party line" or cherished beliefs or even mere loyalty (Kahn and Mann 1957). When a problem is first discovered in an organization there is a tendency to look for a solution that can be controlled within the organization. An administrator may initially bar analysts from considering certain kinds of alternatives for no better reason than that "we don't do things that way." Staff analysts are particularly vulnerable to biases of this sort.

Another thing that can happen is that the analyst in talking with the decisionmaker or his staff becomes aware that the decisionmaker or his superior doesn't like certain kinds of alternatives. He may get the feeling that it is not only useless but also hazardous to even give the impression that he might be advocating these alternatives as possible solutions. As a result, the development of these alternatives is likely to be neglected or forgotten.

Various alternatives can also be advocated by enthusiasts, each of whom quite honestly believes that this alternative is the royal road to the problem's solution. One could easily imagine, in the blood-supply example, one enthusiast advocated all blood being delivered to the hospital blood banks on a prescheduled basis, with another advocating with equal enthusiasm that all deliveries be made on demand. With the analysis in hand, we now know that the best compromise is a set schedule supplemented by a few demand deliveries when blood-bank supplies run short—in short, a hybrid option with an average of 4.2 deliveries per hospital per week, two-thirds prescheduled and the other one-third on demand. Similarly, any citizen with even passing interest in the energy problem recalls that various enthusiasts advocate singular solutions. One of the most vocal groups feels that solar energy is an early prospect that the world must adopt. On the other hand, perhaps the most important finding of the IIASA energy systems analysis is that—at least for the next 50 years—no one energy option can be relied on to solve the world's energy supply problem; rather, a large spectrum of such options, as Figure 3.10 suggests, must be combined appropriately, with the totality managed with a view to having a completely sustainable system within the next century. In sum, the enthusiastically sponsored unitary solar option cannot do the job within the next 50 years, according to the IIASA study.

Alternatives need not represent the same approach to obtaining the objective. Suppose, for instance, the objective were to reduce crime. There are at least two categories of alternatives that might help to attain this goal—social measures such as preventive education and antipoverty legislation or police measures such as severer punishment and more certain apprehension of law violators. In the investigation, police measures as whole might be one alternative, or a specific police measure such as a 50 percent increase in the number of police cars might be another, or a combination of several police measures with social measures might be a further alternative.

The point is that a lot of thought has to be given to the design of alternatives. They will be eliminated or modified to remove or add certain features as constraints are discovered and applied, or as their effectiveness is estimated. Preliminary evaluation in addition can be used to eliminate the grossly inferior and those that are dominated by other alternatives. During the evaluation process the good features of the better alternatives may suggest ways for the analyst to design new and still better alternatives.

Once we have a model or set of models that enables the analyst to determine the significant consequences of a class of alternatives, the analyst can investigate how the spectrum of consequences changes with changes in the alternatives (being careful of course not to make the changes so radical that the credibility of the model is brought into question) and thus improve some of the alternatives. The analyst must, however, not try to carry this process too far, for, although the model results may show differences, they may really be insignificant considering how crude our models are likely to be. There are, of course, certain relatively narrow problems that permit a closed mathematical formulation or model where an algorithm of one sort or another, linear programming for instance, permits the analyst to investigate all alternatives of a certain class and designate one as best. There are few, if any, sociotechnical problems where such a formulation is possible, however.

As noted in Chapter 4, there are usually a number of characteristics or unstated objectives that a decisionmaker expects or would like the alternatives he selects to attain in reasonably high degree: insensitivity, reliability, invulnerability, and flexibility are some of these desired characteristics.

The deliberate generation of a wide range of alternatives is an essential step in systems analysis. One cannot investigate all of them thoroughly; it would be too costly and excessively time-consuming. Moreover, one could not then expect the client to look over the results. Some form of screening that reduces the number of alternatives to something like ten or less should be applied. Dominance or almost dominance may get rid of a few. Eliminating those with some important negative impact such as cost excessively large is another possibility. Elimination based on the analyst's judgment of a group of impacts is a further possibility; one can set up a set of standards based on five or six characteristics and those that fail to meet these standards can be judged not good enough (Eilon 1972).

The final few alternatives that survive this screening may then have to be examined in even more detail. In fact, even after the selection is made, there may be aspects of the chosen alternative that need to be worked out in greater detail before the final program for implementation is prepared.

Strong alternatives make for easy analysis. An outstandingly good alternative may make further analysis unnecessary; it may simply look so superior that acceptance is immediate.

In sum, it is important to begin the analysis with good alternatives, and the time and effort needed to develop them must be adequate to the task, and all of the relevant sources of technical expertise must be tapped in the process. On the one hand, the analysts should beware of the glib technologist who alleges that there are only two or three possibilities; on the other, he should be equally suspicious of alternatives developed entirely within the systems analysis team, for it will usually not contain representatives of all of the useful technologies. Rather, it is a synthesis that is called for, led by the systems analysis team with its eye clearly on the problem in hand.

However, most important of all is the continuing awareness of the need for newer and better alternatives throughout the analysis that frequently holds the key to outstandingly useful results. The IIASA energy analysis team concluded that "The demand for liquid fuels is a principal driving force of the energy problem." Their hybrid coal gasification and liquification scheme is an important step toward solving this driving problem.

REFERENCES

Arrow, K.J. 1951. *Social Choice and Individual Values*. New York: Wiley.

Dror, Y. 1975. Some Features of a Meta-Model for Policy Studies. *Policy Studies Journal*, *3*, 3 pp 247-255.

Eilon, S. 1972. Goals and Constraints in Decisionmaking. *Operational Research Quarterly*, 23,(1) 3-15.

Energy systems Program Group of IIASA, Wolf Haefele, Program Director, 1981 *Energy in a Finite World: Volume 1. Paths to a Sustainable Future*. Cambridge, Massachusetts: Ballinger Publishing Company.

Hatry, H.P. 1970. Measuring the Effectiveness of Nondefense Public Programs, *Operations Research*, 18,5,p 774.

Hitch, C.H. and R. McKean, 1960. *The Economics of Defense in the Nuclear Age* Cambridge, Mass: Harvard University Press.

Hovey, H.A. 1968. *The Planning- Programming Approach to Government Decisionmaking* New York:Praeger.

Kahn, H. and I. Mann, 1957. *Ten Common Pitfalls*, RM-1937, Santa Monica, California: The Rand Corporation.

Keeney, R.L. and H. Raiffa, 1976. *Decisions with Multiple Objectives: Preference and Value Tradeoffs*. New York:Wiley.

Majone, G., 1978. The ABC's of Constraint Analysis, Working Paper No 2, New York:Russell Sage Foundation.

Nagel, S.S. and M. Neef, 1979. *Policy Analysis:In Social Science Research*, Beverly Hills, California:Sage Publications.

Raiffa, Howard 1964. *Decision Analysis: Introductory Lectures on Choices under Uncertainty*. Reading, Massachusetts: Addision-Wesley.

Simon, H., 1964. On the Concept of Organization Goal, *Administrative Science Quarterly*, Vol 9, No 1.

Sugden R. and A. Williams, 1978. *The Principles of Practical Cost- Benefit Analysis* Oxford, England: Oxford University Press.

Walker, W.E., J.M. Chaiken, and E.J. Ignall, 1979. *Fire Department Deployment Analysis: A Public Policy Analysis Case Study*, New York, North Holland.

Wohlstetter, A. 1964. The Analysis and Design of Conflict Systems. In E.S. Quade (ed.), *Analysis for Military Decisions*. Amsterdam: North-Holland, p. 123.