HANDBOOK OF SYSTEMS ANALYSIS

VOLUME 1. OVERVIEW

CHAPTER 1. THE CONTEXT, NATURE, AND USE OF SYSTEMS ANALYSIS

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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 1. 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 1. THE CONTEXT, NATURE, AND USE OF SYSTEMS ANALYSIS

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1. INTRODUCTION

Many of the functions of society involve structures that can be thought of as systems combining people and the natural environment with various artifacts of man and his technology. Such sociotechnical systems abound in modern society: the highway traffic systems, combining drivers and passengers, pedestrians, highways, vehicles, the customs and rules of the road, the weather, and the surrounding environment; the energy system of a country, combining sources of energy, the means for converting these sources to usable forms, the distribution devices and procedures, the using community and the ways it employs energy, and the surrounding natural and economic environment that affects energy use and that is, in turn, affected by the energy system; urban settlements, combining people and their dwellings in a natural environment, their enterprises, their social services, their means of transportation and entertainment, their economic means for exchanging their own labor for products, the laws and customs that govern the system's behavior, and the organizational structures that make the whole work; business enterprises, bringing together capital, labor, management, and specialized knowledge to create products desired by the society in which the enterprise is embedded; and large governmental structures, with their purposes, constituencies, services, funding needs, and relations to the public.

Many elements of such systems exhibit forms of regular behavior, and scientific scrutiny has yielded much knowledge about these regularities. Thus, many problems that arise in sociotechnical systems can be addressed by focusing such knowledge in appropriate ways by means of the logical, quantitative, and structural tools of modern science and technology. The craft that does this is called systems analysis in this handbook: it brings to bear on sociotechnical problems the knowledge and methods of modern science and technology, in combination with concepts of social goals and equities, elements of judgment and taste, and appropriate consideration of the larger contexts and uncertainties that inevitably attend such problems.

The central purpose of systems analysis is to help public and private policy makers to solve the problems and resolve the policy issues that they face. It does this by improving the basis for their judgment by generating information and marshaling evidence bearing on their problems, and, in particular, on possible actions that may be suggested to alleviate them. Thus, commonly, a systems analysis focuses on a problem arising from the operations of a sociotechnical system, considers various responses to this problem, and supplies evidence about the costs, benefits, and other consequences of these responses.

The purpose of this chapter is to provide an introductory description of systems analysis. To this end, it contains discussions of the kinds of issues and problems that systems analysis addresses, the kinds of complexities and difficulties that arise, the central characteristics of a systems analysis, the role that science and technology play in systems analysis, what it does, where it finds application, the value that it has for society and those responsible for solving its problems, and the art of carrying through a systems analysis. The later chapters of this handbook extend the discussions of these points.

2. THE CONTEXT

Systems analysis can be applied to a wide range of highly diverse problems, and the patterns of analysis exhibit a corresponding diversity, depending on the context, the nature of the problem, the possible courses of action, the information needed, the accompanying constraints and uncertainties, and the persons who may use its results.

To illustrate this diversity, this section describes several problems to which systems analysis has been applied: improving blood availability and utilization, improving fire protection, protecting an estuary from flooding, achieving adequate amounts of energy for the long-range future, providing housing for low-income families in the United States, and controlling a forest pest in Canada.

Improving blood availability and utilization. Human blood, a living tissue of unique medical value, is a perishable product: in the US it has a legal lifetime of 21 days, during which it can be used for transfusion to a patient of the same type, and after which it has to be discarded. It is collected in units of one pint from volunteer donors at various collection sites such as a Regional Blood Center (RBC), and after a series of typing and screening tests it is shipped to Hospital Blood Banks (HBBs) in the region of the RBC. Once at the HBB, a unit is stored and is available to satisfy the random daily demand for transfusions to patients. Since not all units demanded and assigned to a patient are generally used, a unit can be issued several times during its lifetime until transfused or outdated and discarded.

The efficient management of blood resources in a region is a difficult task. The blood distribution problem is complex, owing to blood's perishability, to the uncertainties involved in its availability to the RBC, and to the random nature of the demands and usages at each of the HBBs. Superimposed on these complexities are the large variations in the sizes of the hospitals—and therefore the HBBs—to be supplied, in the relative occurrences of the eight different blood groups, and in the mix of whole blood and red blood cells called for. Finally, on the one hand there is the imperative of having blood available when and where needed (while elective surgery can be postponed because of a blood shortage, this act incurs additional costs for all concerned), while on the other hand there is the desire to operate efficiently and economically.

The two most common performance measures for an HBB are the shortage rate (that is, the proportion of days when supplementary unscheduled deliveries have to be made to satisfy the hospital's demand) and the outdate rate (that is, the proportion of the hospital's blood supply that is discarded owing to its becoming outdated); and suitable calculations will convert these measures for hospitals to similar ones for a region. For example, a number of years ago, it was common for regional outdate rates to be 0.20.

In 1979 two systems analysts in the United States reported a study that went most of the way toward solving this problem of managing blood supplies efficiently. After studying the patterns of demand and supply, they were able to characterize the situation with relatively simple models, on the basis of which they were able to devise a decision support system for an RBC that addresses these questions: What are the minimum achievable outdate and shortage rates that can be set for the region? What distribution policy will achieve these targets? What levels of supply are needed to achieve alternative targets?

The blood management system they devised was characterized by centralized management at the RBC, prescheduled deliveries to the HBBs supplemented by emergency deliveries when needed, and a distribution policy according to which some blood is rotated among the hospitals. The operation of this system is based on a mathematical programming model whose objective is to optimize the allocation of the regional blood resources while observing policy constraints.

The final step was to implement this Programmed Blood Distribution System (PBDS) in a trial region on Long Island, near New York City. Before PBDS came into effect, an average of 7.8 blood deliveries were made per week to each hospital in the region, all unscheduled, and the outdate rate was 0.20. After PBDS was implemented, the average number of deliveries dropped to 4.2, of which only 1.4 were unscheduled, and the average outdate rate fell to 0.04, which appears to be about the lowest possible for this situation (some wastage being an inevitable consequence of the random demand and limited supply). These management improvements represented substantial cost savings.

Finally, the analysts designed the PBDS so that it can easily be adapted to new regions, and such adaptations are now in progress.

Chapter 3 describes this outstandingly successful example of systems analysis in somewhat more detail.

Improving fire protection. Fire protection is a basic municipal service. In the face of significant increases in demands for firefighting services, the size of the firefighting force and its distribution throughout a city impose important policy decisions on a city government: How many fire companies to support, where to locate them, and how to dispatch them. A policy that leads to rapid responses with appropriate firefighting resources can save lives and reduce property losses significantly.

The trouble is that there is little agreement on just what is "appropriate." In order to evaluate alternative deployment policies, both performance measures and models to use in calculating values of the measures are needed. Fortunately, in the 1970s a team of systems analysts in New York City was developing such measures and models, which they have been able to apply in several cities.

The fundamental difficulty faced by the analysts was that for this context there are no simple performance measures that can be used, such as the directly observable shortage and outdate rates in the case of blood management.

Since a fire department's primary objectives are to protect lives and safeguard property, the most important measures of its performance are the numbers of fire fatalities and injuries, and the value of property lost in fires. It is not possible, however, to use these measures to evaluate different deployment policies because there are as yet no reliable ways to estimate the effects that different policies have on them. For example, if the number of fire companies on duty were doubled (or halved), no one can say with a satisfactory degree of confidence what effect the change would have on the number of fire casualties or property losses. The direction of the effects on these measures may be predictable for large changes, such as doubling or halving, but the quantitative (practical) consequences are not—and in the case of more realistic small changes in deployment policy, neither the direction nor the size of the change in casualties or damage is predictable.

Therefore, in order to evaluate alternative firehouse configurations, the analysts developed three substitute, or "proxy," measures, the first two of which are directly related to loss of life and property damage: (1) travel time to individual locations, (2) average travel time in a region, and (3) company workload. Changes in the numbers of firehouses and their locations have consequences that appear as changes in the values of these measures. The consequences can therefore be evaluated against the background of other considerations, such as hazards, fire incidence, costs, and political constraints.

The analysis team put its approach to work in an assessment of the firefighting deployment in the City of Wilmington, Delaware, USA. In 1973 Wilmington had eight firehouses, all but one of which antedated 1910. This fact, together with the city's growth and evolution, suggested a fundamental reexamination of the firefighting deployment, which was undertaken.

In conducting such a study a great deal of data must be collected about the city and its fire and firefighting experience, but, for our present purposes the two chief categories are travel times from one location to another in the city and the demand for firefighting services (fire alarms and actual fires).

With this information in hand the analysts proceeded to their analysis, using principally three tools that had already been developed.

1. A simple formula for the relation between travel time and distance, valid in spite of the pattern idiosyncrasies of the city.

2. A Parametric Allocation Model that determined fire company allocations that would satisfy a wide range of objectives and permit them to be evaluated in terms of average regional travel times, average citywide travel times, and company workload. This model incorporates a simple formula that specifies the number of companies that should be allocated to each region, given the total number of companies to be deployed in the city and a parameter that reflects the desired objective.

3. The Firehouse Site Evaluation Model, which dealt with the question, given a particular number of engine and ladder companies to be deployed in a region, where should they be located?

Perhaps the most important fact for us to note about these models is that they do not allow the analysts to retire to an ivory tower to select the optimal configuration for the city. Rather, they must be used cooperatively with the city officials who can specify objectives that should be met, and who can judge the worth, not only of the values of the proxy output measures calculated by the analysts for the options explored, but also the many other factors bearing on the possibilities that are not embodied in the models.

For Wilmington, the results of the analysis suggested that the number of engine companies could be reduced by one or two and that the remainder could be repositioned with little effect on fire protection. Finally, the recommendation was that one company be eliminated and five of the remaining seven be relocated.

This recommendation was adopted, but then followed by lengthy negotiations with the firemen involved, which were successful. The result is a firefighting force as effective as before, but with the costs significantly reduced.

Chapter 3 discusses this case in more detail.

Protecting an estuary from flooding. In 1953 a severe North Sea storm flooded much of the delta region of the Netherlands, killing several thousand people. Determined not to allow this to happen again, the government started a program to increase the protection from flooding by constructing a new system of dams and dikes. By the mid-1970's, this system was complete except for protecting the largest estuary, the Oosterschelde. Three alternatives for this task were under consideration: building an impermeable dam to close off the estuary from the sea, building a flow-through dam with gates that could be closed during a storm, and building large new dikes around the estuary.

In 1975 the Netherlands Rijkswaterstaat (the government agency responsible for water control and public works) and the Rand Corporation of Santa Monica, California, began a joint systems-analysis project with a view to helping decide what should be done. It set out to determine the major consequences that would follow from implementing each of the three alternatives for protecting the estuary. These consequences, called impacts, were grouped into categories such as financial costs, security from flooding, effects on jobs and profits in the fishing industry, changes in recreational opportunities, savings to carriers and customers of the inland shipping industry, changes in production, jobs, and imports for the 35 industrial sectors of the national economy, changes in the species and their populations that comprise the ecology of the region, and, finally, as social impacts, the displacement of households and activities and the disproportionate effects on the regional economies. A major uncertainty was the severity and frequency of the super-storms that make the provisions for protection necessary. Not surprisingly, no one of the three alternatives turned out to be uniformly better or worse than the others when the full range of impacts was considered.

By intention, the study did not conclude by recommending a particular alternative. Rather, it clarified the issues by comparing, in a common framework, the many different impacts of the alternatives, but left the choice among the alternatives to the political process, where the responsibility properly resides. There was no dominant alternative; rather, each was found to have a major disadvantage that might be considered serious enough to render the alternative politically unacceptable: The storm-surge barrier alternative (that is, the flow-through dam) was by far the most costly, the impermeable dam was the worst for the ecology, and the open case with new dikes around the estuary lacked security.

The Rijkswaterstaat supplemented this work with several special studies of its own and submitted its report to the Cabinet, which recommended the more costly storm-surge barrier plan.

Chapter 3 offers a more extended discussion of this work.

Achieving adequate amounts of energy for the long-range future. The goal of systems analysis is to be as comprehensively relevant as feasible, and to produce findings that are as completely specified as the practical need dictates. However, such precision is possible only when the analysts have scientific knowledge that is sufficiently comprehensive to make a complete and strong foundation for the analysis and its results. Regrettably, all too often the knowledge is partial or sketchy, or even nonexistent, especially in cases looking far into the future or where the system of concern depends on the actions of individuals or social groups whose behavior is not yet well understood by science. In such cases, a model encompassing the full problem cannot be constructed, but, nevertheless, systems analysis can make important contributions to knowledge and policy. One approach to the problems of a sociotechnical system whose complexities are not fully understood is shown by the next example.

Wolf Haefele and a group of colleagues at IIASA have completed an inquiry into the long-range energy strategies that the world should pursue. Rather than attempt to design a global energy policy, their more modest aim was to provide information on energy to the world's nations, so that through their actions, alone or in concert, an equitable and far-sighted policy will evolve. Here, in place of the relatively simple blood-supply system of a previous example, we are confronted with complex interactions among the technologies, economies, environments, resources, people, social attitudes, and ambitions of many nations. Instead of a relatively homogeneous region, we have the full globe. And in place of relatively few decisionmakers, we have a very large number of independent policy makers in private industry and national governments, and in international enterprises and organizations.

The role of systems analysis in this setting is not to determine a single best policy for a single decisionmaker, but to provide a broad perspective for autonomous decisionmakers to use in making their choices. The analytic approach is to identify and improve our understanding of the important interactions among energy-system components, among the policies of nations and industries, and among energy choices over time for the next fifty years or more. Many models are involved and the work demands much data collection and many analyses.

Rather than a single comprehensive computational model—impossible because of the lack of knowledge and the sheer size and complexity of the world energy system—Haefele and his team constructed an overlapping, interlinked series of investigations of such subquestions as:

- What will the evolving pattern of demand for energy be?
- What resources will be available to satisfy the demand?
- What technological options will be feasible?
- What constraints will limit selections among the options?

Instead of a quantitative evaluation of alternative policies, the analysis team identified a spectrum of strategies responsive to different possible national, international, and industrial goals. As in many analyses, the analysts sought a synthesis—the invention and design of new alternatives, courses of action that will satisfy specified demands and constraints and achieve given goals as nearly as possible. The hope is that, armed with this knowledge, and the new alternatives emerging from the work, many decisionmakers will choose improved policies, not from their short-term parochial standpoints, but also from a broad systemic viewpoint.

Chapter 3 gives a fuller account of this study of the future of the world's energy system.

Providing housing for low-income families. Still other approaches may be necessary in certain problems. For instance, a policy maker may feel a need to intervene in a social situation but must avoid introducing extraordinary disruption or creating a costly program that, if it fails to achieve its purpose, may become politically impossible to discontinue. For such a situation, a social experiment may be the technique to apply since, of all methods, controlled experiments allow the strongest inferences about causality.

Consider the systems analysis based on a carefully planned experiment now (1980) being carried out under contract for the United States Department of Housing and Urban Development (HUD). Its purposes are to evaluate the idea of providing housing assistance to low-income families by means of direct cash payments and to predict market and community responses to a full-scale housing assistance program of this type.

For more than 40 years, United States policy makers have sought to find ways of providing housing assistance to low-income families that would be cost-effective, efficient, and equitable. Rental housing built and operated by local authorities, privately owned housing leased by public authorities, mortgage-interest subsidies to private landlords on behalf of their tenants, interest subsidies to low-income home purchasers, and other schemes have been suggested, argued about, analyzed, and, in some cases, even tried out, with results that have not warranted their large-scale adoption. In the early 1970's the idea of direct cash payments became prominent. It looked good on paper, but there was considerable opposition, based on disparate predictions as to how it would affect the housing market and the communities in which it would operate. Many feared an escalation of rents, speculation in real estate, rapid turnover of neighborhoods, and hostility from those who would not be allowed to benefit from the program. Some foresaw that it would lead to deteriorating neighborhoods, some were afraid it would hasten racial integration, others that it would reinforce segregation. Consequently, the analysts proposed an experiment to gather the key information for their systems analysis.

An analysis contractor designed a controlled social experiment and launched it in two metropolitan areas in the midwestern United States. The areas were chosen for contrasts in housing-market characteristics such as vacancy rates and residential segregation. Nearly 15,000 households were enrolled by the third year of the program.

Data from the experiment, plus market data collected as part of the analysis, provide a basis for measuring how the attempts of program participants to improve their housing affect rents, housing prices, and housing quality in the experimental sites; how local businesses and institutions respond to the program's addition to low-income demand; how participants move and how their neighborhoods are affected; and how community and nonparticipant attitudes are changed. Since the experiment is not yet completed, it is too early for many conclusions. However, the predictions of extreme changes turned out to be wrong. At neither site has there been a significant disturbance of the housing market or of neighborhood settlement problems, and at both sites the program is generally approved by public officials, civic leaders, landlords, real-estate brokers, mortgage lenders, and most citizens who know of it.

Lowry (1977) summarizes the key features of this experiment and its early results.

Controlling a forest pest in Canada. Some systems problems are characterized, not only by limited knowledge, but also by short time horizons over which reliable predictions can be made and conflicting interests that cannot be resolved by bringing them under a common administrative framework. A forest-pest control problem studied by C.S. Holling and a team of analysts from IIASA and the University of British Columbia provides an example.

The boreal forests of North America are devastated periodically by a defoliating insect called the spruce budworm. An outbreak can kill a large proportion of the mature softwood forest, with major consequences to employment and the economy of the region. Extensive spraying has succeeded in reducing tree mortality, but at the expense of maintaining incipient outbreak conditions over a considerably more extensive area.

The problem, as originally conceived, was to investigate and design alternative policies, to be implemented by the government, logging enterprises, and landowners, and to evaluate their effectivenesses in controlling the spruce budworm. The study objective was to determine which policies should be adopted in order to achieve the most desirable consequences.

These policies, which involve decisions about tree planting, cutting, and spraying, are difficult to formulate, because any change in such policies yields a new pattern of budworm infestation and tree growth and a changed harvest, affecting economic costs and benefits for individuals, business, and government; there are also social and recreational impacts on people less directly concerned.

Without systems analysis, or its equivalent under some other name, the decisionmakers would have had to rely upon their intuitions and their previous experiences—perhaps supplemented by opinions from specialized experts—to design policies and to select the most promising for implementation. But intuition, experience, and specialist opinion are severely limited when systems have complex interactions spaced widely in distance and in time, as the budworm-forest system does.

Systems analysis is able to provide help in the budworm case because biologists, foresters, and ecologists have learned enough about the spruce forest and the budworm to be able, under most conditions, to predict their responses to changes in the environment. Holling and his colleagues have used this knowledge to construct an interrelated set of models that enable computer calculations to simulate with acceptable accuracy the behavior of the forest and the budworm under a broad range of changing conditions. These models make it possible to try out, by means of computer simulation, many policies that could be proposed. While the models cannot guarantee that their predictions will be the results that would occur were the policy to be implemented in the real forest, checking the model with historical data has given its users confidence in its predictions. With the information provided by this analysis, the decisionmakers are in a better position to select from the options they face the one that best serves their needs.

Recently, owing to the analogies that this work offers with other pest-control and environmental problems, Holling and his colleagues have broadened their interests to include environmental management in general. However, because of the uncertainties and knowledge gaps that have attended this broadened inquiry, their emphasis has moved away from set and well described policies toward more flexible "adaptive policies," as described in a volume edited by Holling (1978).

In recent years, Holling and his team have devised a workshop approach that involves representatives of key interests in an interaction with the analysts and their models periodically over as much as a year to evolve common understandings and both preferred and acceptable courses of feasible action leading to desirable objectives. *Expect the Unexpected: An Adaptive Approach to Environmental Management*, IIASA Executive Report 1, issued in 1979 offers an introduction to this approach.

Checkland (1981) has pioneered a similar approach to the problems of business firms.

Both of these developments are harbingers of the day when systems analysis will have extended its frontiers well beyond its presently well understood arena of sociotechnical systems to systems in which individual human behavior is much more dominant than in the ones usually studied today—and which are the central focus of this Handbook.

3. THE NATURE OF THE PROBLEMS

These examples all deal with sociotechnical systems: The blood-supply system consists of the human donors, the Regional Blood Centers, the Hospital Blood Banks, and the hospitals and patients using the blood, as well as the medical and administrative staffs who manage these activities; the firefighting system consists of the city and its population, the fires that occur and their properties, the firefighting forces, the city administration, and the weather conditions in which the activities are embedded; the forest-pest control analysis dealt with a system consisting of the forest, the insect pest, the lumbering industry, and the economy and society of the region, all embedded in the area's environment; the world's energy system consists of the sources of energy, the means of transforming them into practically usable forms, the ways of transporting the energy to the points of use, the economies of the world's nations, the population of energy users, and the operations that energy fuels, all embedded in the natural environment that affects energy use, and that is, in turn, affected by the way the energy is used; the housing-assistance experiments operate in urban areas—and hence are embedded in their operations and economies—and include the housing units, the families occupying them, the owners of the units, and the communities in which they are located; the Netherlands flood-control system includes not only the sea, the land, and the engineering works aimed at controlling floods, but also the population of the region and its operations, the ecology of the area, and the Netherlands economy, all embedded in the social and natural environment of the region.

All of the cases exhibit phenomena widely distributed in both space and time: the pest-control study considered an area of 4.5 million hectares and, because the intervals between outbreaks of the forest pest range from 30 to 45 years, a time period of from 80 to 160 years; the energy study considered the entire world's production and consumption of energy between now and 50 years into the future.

In each of the cases many variables had to be considered—so many, indeed, that it is neither feasible nor desirable to attempt to set forth even an abridged list here. However, Chapter 3, where four of these examples are discussed more fully, gives an idea of the principal issues and variables considered.

From these cases, one can also imagine how, as one considers what may appear to be a simple problem, the aspects that need to be considered proliferate. For example, the spruce budworm is a damaging forest pest, and the "obvious" thing to do to reduce the damage it causes is to attack it. However, a spraying program against the pest, although successful in reducing its damage to the forest in the sprayed areas, was found to have a number of unhappy effects: the area of incipient outbreak widened significantly and the spray produced undesirable environmental effects, including threats to human health. Thus, it became necessary to consider the budworm cycle in its forest habitat in some detail, which involved the analysts in the forest's natural cycle. Then, since an important reason to preserve the forest is to enable the lumber industry to remain healthy and productive, one must consider it, and hence the economy of the region to which it is an important contributor, particularly since the cost of any forest-management program must be levied against the resources of the region through taxes or otherwise. And so on.

The complexities of each of these problems, and the large numbers of people concerned with how they are solved, make it clear that many decisionmakers are involved, many people's interests are affected, and many constituencies may have competing objectives (for example, environmentalists may want to preserve the beauty and integrity of the forests, while lumbermen want to have its timber available for cutting).

And all of the problems are attended by many uncertainties: weather patterns affect the sea's threat to the coastline regions of the Netherlands, as well as the spruce budworm cycle; unforeseen political and technical developments will almost certainly impact the world's energy situation in the future. Indeed, uncertainties are quite often present, and frequently irremovable, particularly when they arise from the natural environment or the goals of individuals, social groups, and countries.

Against this background of complications, the analyst seeking a successful application of systems analysis may have to overcome one or more of these difficulties:

- Inadequate knowledge and data

Sometimes, even though the problem may be of long standing, data may be lacking or incorrect, cause-and-effect relations may be obscure, and no relevant literature or even theory from which to start may exist. Those with responsibilities for resolving the problem may have no mental model of processes involved and thus lack an intuitive feeling as to the outcome. Well-known "facts" may be wrong. As Holling observes (1978, page 97): "The [budworm] model predicted that the forest would decline independently of insect damage, while it was 'common knowledge' that volume was high and would remain so if insects were controlled. We spent 2 months checking the model for errors when we should have been spending 2 days looking at the available raw data on forest volume. When we belatedly took this obvious step, the model was vindicated."

- Many disciplines involved

Most sociotechnical-system problems require scientific and technical knowledge from many different specialties. A multidisciplinary team is needed, a situation fraught with difficulties, for true interdisciplinary work is often hard to carry out. For example, the forest-pest analysis and the ensuing work of applying its findings required inputs from biology, zoology, forestry, mathematics, operations research, ecology, business, economics, and public administration, among others—and professionals in all these fields participated in the work.

- Inadequate existing approaches

When this is the case new methods may have to be invented, developed, and tested. Existing approaches have frequently been developed within a single discipline by borrowing ideas from other disciplines without truly integrating them. A trial-and-error approach may be available theoretically, but, as a practical matter, it may be prohibitively costly or too risky.

- Unclear goals and objectives

To help decision and policy makers it is crucial to know what they want. While they usually have an idea of what is desirable, their statements of goals are often too vague to serve as useful guides to systems analysis, or as criteria to guide one's judgments of how well actions and programs serve the goals. Indeed, a politician may find an advantage in keeping his true goals concealed, or so general that they have no operational significance. However, in general, goals are a subject people find difficult to think about and make explicit. Thus, one of the early tasks of a systems analysis is often to evolve with those concerned reasonably explicit statements of goals—even though the light shed on them as the systems analysis proceeds may suggest their revision, particularly since one frequently cannot decide what he wants to do until he has some idea of what can be done and what it will cost.

- Pluralistic responsibilities

It almost always happens that, for a problem sufficiently complicated to call for a systems-analysis approach, there are many persons and organizational units with relevant responsibilities and authorities. All six of the examples illustrate this point.

- Resistance to change in social systems

Resistance to change is a property of social systems so common as to hardly call for comment. However, it is worth noting that many forms of institutional structure and government are deliberately designed so as to be resistant to change, so that they will survive even fairly strong perturbations intact. Thus, this fact is an important one for the systems analyst to consider, and his results—usually urging changes in response to the problems that prompted the analysis in the first place—must take careful account of this resistance if they are to find acceptance and usefulness.

- Complexity

The examples we have so far considered all illustrate the complexity of sociotechnical systems. Indeed, it is this complexity that calls for systems analysis to come into play. Thus, one can say that complexity is a characteristic property of the sociotechnical-system problems for which systems analysis is an appropriate approach—and, therefore, the analysis will itself be complex.

This listing of difficult properties of sociotechnical systems is not intended to discourage; rather, it is meant to underscore the importance of having an approach to the problems of such systems that has proven usefulness. The history of systems analysis offers many cases where this approach has helped decision and policy makers with their problems—and, unfortunately, some cases where the hoped-for benefits have not accrued. It is the purpose of this *Handbook* to capture the lessons of this history, and thus offer its readers information about ways to approach such problems successfully, techniques that can help solve them, procedures for seeing the solutions into practice, and pitfalls that should be avoided in the work. Indeed, it is the difficulties that this section has sketched that have undoubtedly made the development of systems analysis come so late in the world's intellectual history—and that provide the rationale and potential usefulness of this *Handbook*.

4. THE CHARACTERISTICS OF SYSTEMS ANALYSIS

Systems analysis is the multidisciplinary problem-solving activity that analysts have evolved to deal with the problems of sociotechnical systems. It did not emerge quickly in response to an appreciation of the importance of such problems; rather, as Chapter 2 shows, it grew on the foundations built by many specialties that dealt with simpler and less taxing aspects of such systems.

It is neither possible nor desirable to define systems analysis in concise and comprehensive terms. Since systems analysis deals with diverse problems and different systems, it assumes many forms adapted to the problems, the systems, and their administrative contexts. To achieve its full growth and usefulness it must continue this process of adaptation and extension, which should not be inhibited by too narrow a conception of what it is or how it fits into the social process of problem solving.

On the other hand, it is useful to describe common features that characterize systems analysis:

- Context–the operations and problems of sociotechnical systems.
- Method–a synthesis of understanding, invention, analysis, design, intuition, and judgment.
- Tools–those of logic, statistics, mathematics, technology, and the sciences, employed by multidisciplinary teams.
- Aim–to lead to an ameliorative response to problems through programs, decisions, actions, and their evaluation.
- Clients–those with responsibilities for and interests in these ameliorative responses.

A complete systems analysis may involve as many as nine steps, although they may have only hazy borders and may occur either in parallel to some extent, or in an order other than the one listed. Applied systems analyses:

1. Marshal both the evidence relating to the problem and the scientific knowledge bearing on it, when necessary gathering new evidence and developing new knowledge.
2. Examine critically the social purposes–of both persons and institutions–relating to the problem.
3. Explore alternative ways of achieving these purposes, which often include designing or inventing new possibilities.
4. Reconsider the problem in the light of the knowledge accumulating during the analysis.

5. Estimate the impacts of various possible courses of action, taking into consideration both the uncertain future and the organizational structures that must carry forward these courses of action.

6. Compare the alternatives by applying a variety of criteria to their consequences.

7. Present the results of the study to all concerned in a framework suitable for choice.

8. Assist in following up the actions chosen.

9. Evaluate the results of implementing the chosen courses of action.

The first example discussed in this chapter, which dealt with improving blood availability and utilization, is an excellent example that exhibits all of these steps; to complete this long chain the analysts took several years in cooperation with officials at many levels in the organizations with which they dealt. Similarly, the fire-protection example also exhibits all of these steps except the last, which is not mentioned in the description; the estuary-protection example also exhibits this outline of steps (while the last two are not clear from the short description here, the analysis team did assist in following up the actions chosen, but, of course, the evaluation of the results of the final implementation must await completion of the engineering works it calls for).

On the other hand, the other three examples deviate considerably from this outline: the long-range future energy study was forced by the myriad complications of its context to narrow its future to two principal scenarios (with some variants) projecting a world without major surprises or political upheavals, and only further work by national and regional teams could translate its findings into frameworks suitable for choice; the low-income housing experiment was designed to get enough reliable knowledge to permit further analysis and support reasonable short-term decisions; and the forest-pest work must await the slow processes of nature to yield the evaluations that will be the bases for the next steps in the work.

Indeed, although the list of steps refers repeatedly to "the problem," only a rather broad view of what this word can mean allows the discussion to cover the currently available experience with systems analysis. For the blood-supply case, we may perhaps say that the problem was to reduce the shortage and outdate rates, a rather sharply defined problem. However, for the study of the world's future energy supply the situation was a great deal more complex. Originally the analysis team felt that fifty years would be enough to allow the world to effect a transition from reliance on exhaustible fossil fuels for much of its energy needs to renewable sources such as sunlight. However, the study itself showed that this was far too sanguine an expectation, so that the problem was changed to read something like this: Is there a path we can travel over the next fifty years that will lead us successfully toward a sustainable energy future at some later time? But one notices immediately that this is a very broad and general statement, lacking the precision of the one for the blood-supply case. Thus, it is common for a systems analysis to arise from a problem situation, rather than a well defined problem–and, indeed, it may never get much beyond this, if the context is sufficiently complicated. Consequently, for "problem" in many cases we must understand "problem situation," a very important fact for the reader to bear in mind in what follows, even though we will usually speak of "the problem" to avoid complications in the discussion.

The lesson to be learned from these contrasts is that systems analysis cannot hew to an accepted, predetermined outline, but must respond to the conditions in the problem context and exploit such opportunities for assistance to decisionmakers as it may offer. Similarly, the disciplines involved, the methods used, the forms of communication adopted, and the schedule for the work must all respond sympathetically to the needs of the context and the officials with roles to play in it. Good systems analysis can on occasion be short and concise, or long and arduous; it can employ only a bit of common sense, or very complicated mathematics.

It would be unfair to the reader to leave the impression from the six examples we have described that all systems analyses have happy results. For example, the effort to decide on a location for a third London Airport, a large study, considered a great many aspects of its problems, cost one million pounds, lasted more than two years, and employed an elaborate computer model; however, its recommendation was rejected for a variety of reasons, but partly because it was not adequately comprehensive: important environmental considerations were not taken into account.

While it is possible to conceive of a problem of a large-scale sociotechnical system that lies in the hands of a single decision or policy maker, the case where there are pluralistic responsibilities and interests is so much more usual as to be virtually characteristic. Thus, the findings of a systems analysis must, a fortiori, be aimed at—and be communicated to—this varied community of persons. This fact provides systems analysis with another important role: unifying the knowledge base, logical framework, and overall perceptions of this community.

Indeed, there is a case to be made that, in many situations, a systems analysis is part of a social process of problem solving in which many people take part. In this conception, the analyst affects the social and operational environment of which he is a part, which in turn affects the problems that he is asked to work on, and how he goes about his analysis. The argument for this point of view has been developed by a number of advanced thinkers in the field as being an important aspect of the future of systems analysis; Steen Hildebrandt (1979) provides an excellent introduction to the point of view and the literature that supports it.

5. SCIENCE AND SYSTEMS ANALYSIS

Science and its knowledge are the cornerstone of systems analysis, but systems analysis itself is not science. The purpose of this section, therefore, is to clarify the relations between science and systems analysis, and to show how systems analysis depends on science for its strength.

The domain of science is the phenomena of nature in the universe and the world. This context includes not only the phenomena described in the classic sciences with which we are familiar (astronomy, physics, chemistry, psychology, biology, zoology, and so on), but also the less well understood phenomena of social and sociotechnical systems.

John G. Kemeny (1959), in *A Philosopher Looks at Science*, describes the method of science in this way:

> As Einstein has repeatedly emphasized, Science must start with facts and end with facts, no matter what theoretical structures it builds in between. First of all the scientist is an observer. Next he tries to describe in complete generality what he saw, and what he expects to see in the future. Next he makes predictions on the basis of his theories, which he checks against facts again.
>
> The most characteristic feature of the method is its cyclic nature. It starts with facts, ends in facts, and the facts ending one cycle are the beginning of the next cycle. A scientist holds his theories tentatively, always prepared to abandon them if the facts do not bear out the predictions. If a series of observations designed to verify certain predictions, force us to abandon our theory, then we look for a new or improved theory. Thus, these facts form the fourth stage for the old theory as well as the first stage of the new theory. Since we expect that Science consists of an endless chain of progress, we may expect this cyclic process to continue indefinitely.

As a matter of practice, the systems analyst (and many of the scientists who contribute knowledge to his work) speak of their theories as "models"—but the terms are synonymous.

We then define science as the body of knowledge (or collection of facts and models) assembled by the method of science. The individual sciences are distinguished by the portions of nature they are seeking explanations for, rather than their techniques, tools, or methodological approaches, although these may have somewhat characteristic associations with particular sciences.

Workers setting out to apply the knowledge gained by science may find the way to use the knowledge is simple and direct; however, it is more usual for them to have to invent some sort of practical instrumentality to exploit their knowledge. In fact, for all but quite simple problems, they have to bring together much such knowledge and many inventions by designing a synthesis of a variety of items of knowledge and adapting the individual inventions to the new synthesis; almost any of today's high-technology artifacts (such as airliners) illustrate this point.

These invention and design activities aimed at applying the knowledge of the physical sciences are what are usually meant by the term engineering. Over recent decades there has been a tendency for the various classic branches of engineering to remain closely tied to the sciences on which they depend for the knowledge they use. It is also important to note that many engineering artifacts are involved in the sociotechnical systems that systems analysis is concerned with.

However, there are newer scientific activities that are investigating phenomena exhibited by sociotechnical systems that have not been incorporated in older sciences; the operations-research explorations of man-machine operating systems are notable examples.

Analysts looking over the scientific knowledge available during the last quarter century and the efforts to use this knowledge to design solutions to large-scale sociotechnical-system problems saw the need for the classic and newer fields of science and technology to work together to solve these larger problems; this impetus led to systems analysis.

Against the background of this discussion, systems analysis can now be described as the invention and design—or engineering—art of applying scientific knowledge to the problems of sociotechnical systems.

Thus, while systems analysis contains many scientific components, it is not itself a science; rather, it is a new form of engineering being applied to the problems of large-scale sociotechnical systems—it is concerned not only with theorizing, but also with choosing and acting. However, it uses the methods of science in so far as possible and strives to uphold similar traditions. That is, good practice holds that:

- Results emerge from processes that can be duplicated by others to obtain the same results.

- Calculations, assumptions, data, and judgments are reported explicitly, and thus are subject to checking, criticism, and disagreement.

- Conclusions are not influenced by personalities, reputations, or vested interests.

Certain sciences—economics, sociology, and physics, to name a few—are particularly relevant to the problems that systems analysis addresses. Other disciplines—logic, mathematics, engineering, and computer science, for instance—provide the tools. Among the latter, operations (or operational) research is particularly significant, because it is the discipline from which modern systems analysis emerged and because it shares a set of tools with systems analysis.

Systems analysis, as a name, may be relatively new, but it is not a new concept or activity. History records a number of past analytic efforts that, if carried out today, we would call systems analysis. The genesis of systems analysis as we mean it here (at least in the United States, where it became widespread in the defense and aerospace industries in the fifties and then throughout the federal government in the sixties) took place in the late 1940's. The term was coined to distinguish research then being done for the US Air Force on future weapon systems from operations research. The work was not operations research (as operations research was then understood) for both the objectives of the systems and the resource requirements had to be determined and the environment in which they would operate predicted. These inquiries were called "systems analyses" because they were concerned with decisions about well defined systems. That an analysis dealt with a "system," however, was neither important to its structure nor to the way what was being done differed from operations research. Part of the difference lay in the need to introduce long-term economic factors and to consider interactions between means and objectives, activities that were not then considered within the scope of operations research. Today, however, operations research has broadened to take into account these considerations and, along with systems analysis, to treat considerations of equity and other political and social concerns.

In fact, as systems analysis is characterized in this *Handbook*, operations research, broadly defined as it is today, is essentially identical with it. Cost-benefit analysis, systems engineering, and prescriptive modeling are also forms that systems analysis can take, but, as ordinarily practiced, they are more limited in scope. All of these activities follow the same general approach to problem solving and, like systems analysis, make use of many of the same disciplines, particularly economics, statistics, and probability theory; they draw upon the same stockpile of tools—linear programming, queueing theory, and the computer, to name a few—and, when the need arises, they employ procedures such as predictive modeling, sensitivity testing, optimization, and decision analysis. Hence, where we speak of systems analysis in the following chapters, others might use a different name for the same activity. In the United States, this name could be policy analysis; in the United Kingdom, operational research.

However, this *Handbook* focuses its attention on problems of systems of larger scale, and thus does not attempt to cover the smaller-scale problems often treated under these other titles.

6. RELATED FORMS OF ANALYSIS

One way to help make clear what systems analysis means in this sense (and thus in the sense in which it developed and in the sense in which it is now most frequently used at IIASA) is to describe what it is not. For one thing, it has nothing to do with classifying systems or with discovering properties common to categories of systems; these are things one might investigate in general systems theory or in systems science. It does not concern itself with specifying the distinction between social systems and cultural systems, for instance. This does not mean, of course, that general systems theory or systems science may not be useful in a particular study. In fact, systems analysis need have nothing whatsoever to do with any system other than the system defined by the activity itself, made up of the things, concepts, and relationships involved in the investigation.

Second, modeling is not systems analysis. A system analysis is an attempt to discern and answer questions of importance in the choice of a decision or policy; a model is merely a useful device in helping to obtain answers to such questions.

Further, systems analysis is not research for knowledge alone, nor is it causal analysis, concerned with discovering the nature and causes of social or environmental problems or the explanations of behavior, although such research may be necessary to a systems study. Systems analysis, in contrast, is concerned with analyzing and resolving issues arising in specific institutional contexts. Systems analysis thus is often a bridge between decision makers and the research community. The latter, for example, may be investigating the effects of economic incentives on work behavior, and a systems analyst, helping decision makers design an income maintenance program, may use this research and thus make it known to policy makers.

Finally, systems analysis is not a branch of applied mathematics—constrained optimization–or a branch of logic–the pure logic of choice–nor does it claim to be identical with what is sometimes called rational decision making or rational problem solving, although the differences may not always be apparent.

The term systems analysis, unfortunately, has several other interpretations. Although the words "systems" and "analysis" are clearly defined and have about the same meaning in all languages, when put together to form "systems analysis," uniformity disappears. Many scientists interpret systems analysis as the analysis of systems—an attempt to explain the behavior of complex systems, that is, as the act or process of studying a system (as a business, a manufacturing plant, a telephone network, or a physiological function) in order to define its purposes and discover how it works. For others it means general systems theory or systems science. For still others who read the help-wanted pages of American newspapers, it refers to the activity of a high-grade computer specialist. A few even define systems analysis as "systematic" analysis; it is hard, however, to think of any analysis as being other than systematic. Also in certain fields, such as business or psychology, systems analysis has even more specialized meanings. Most commonly, however, for us and for the policy research community, systems analysis is interpreted as a guide to decision: a study carried out to bring about a better outcome than would have occurred without it.

7. APPLICATIONS

Systems analysis has been applied with varying success to a wide spectrum of problems, both in type and area. We have systems analyses in the field of education that range from efforts to increase efficiency in the use of space by using computer programs to allocate classrooms for school activities to analyses of educational objectives; in the area of environmental protection from setting the length of the salmon fishing season to designing a wildlife impact reporting system or to choosing among alternative methods of controlling pollution. In concept, it can be applied to any sociotechnical system in which decisions are made or policy set, although, of course, there may be situations where another approach might be more appropriate.

Systems analysis can be put to many uses, routine (optimizing a system for assigning police patrols) or nonroutine (working out the main feature of a housing maintenance plan). It can be used to raise questions about, and explore the consistency among, objectives of different programs (whether a petroleum company should look to further profits from an increase in exploration or from diversifying into other areas beside petroleum). It can point out directions for seeking new knowledge (using solar energy, for instance) and discover new uses for old products (adding a chemical to water to decrease friction through fire hoses). Systems analysis provides this help by bringing knowledge, methods, ideas, and procedures from the academic, scientific, and research communities to bear on problems faced by business, industrial, and political decision makers.

Systems analysis often works well with budgetary decisions. The first studies to which the name was applied were military cost-effectiveness analyses. That is, they were studies that sought to determine a course of action that, for a fixed budget, would most nearly achieve some desired objective, or, conversely, the alternative that would achieve a given goal for the least cost. Budgetary decisions typically involve choices among good things; the problem is to find out which are better. Actually, a good many questions, both public and private, that require analytic help are of this type—say, for example, those involved in an attempt by a city fire department to provide an improved level of protection within its budget. Such questions may require for their answers little more than careful data collection and the skillful application of standard techniques from operations research and economics. These questions typically arise from the desire to increase efficiency in a situation where it is clear what efficiency means. The situation often can be made to fit a well-known model such as linear programming or queueing theory and a near-optimal solution obtained by means of a systematic computational routine.

Systems analysis has been most successful in helping with issues in which science and engineering dominate, as, for example, in many industrial and military applications. Here the problem has usually dealt with a completely man-made and directed enterprise—a manufacturing process, a weapon system, an airline—something that was, or can be, designed with a clear purpose in mind and has a structure that follows known laws of engineering, physical science, and economics. Authority is clear-cut and cooperative, ordinarily believing that analysis can help rather than hinder the situation, and the underlying design can be discovered and modeled.

In contrast, when political, organizational, and social factors dominate, as they do in most public problems, as, for example, in designing a welfare system or in setting standards for pollution control or in defining an urban renewal policy, goals may be obscure and conflicting and authority diffuse and overlapping, with no confidence that analysis can help with the solution. Dalkey (1967) suggests that, because the underlying structure may have grown without conscious design, to discover the underlying model may require the same sort of profound digging that is required to determine something like the role of hormones in regulating body functions.

In addition, efficiency and effectiveness may have no clear meaning in such problems; questions of equity, and "who benefits" and "who pays" may be more critical to the acceptance of a proposed solution than any question of which policy generates the greater surplus of benefits over costs. The difficulties of deciding what ought to be done are likely to dwarf those of finding out how to do it. Nevertheless, systems analysis has helped here, even though it may not have offered a complete solution, by providing information, by isolating alternatives, and by yielding insights that have enabled decision makers to intuit better solutions. Systems analysis of this latter type is now being called policy analysis, particularly in the United States, partly to avoid confusion with the narrow office management and computer uses of the term systems analysis.

8. THE VALUE OF SYSTEMS ANALYSIS

The purpose of systems analysis, as stated earlier, is to help (and possibly to influence) a decision maker to choose a better course of action in a particular problem situation than he might otherwise be able to select. But, to be useful, the analysis does not have to provide him with a complete prescription as to what he should do in every conceivable contingency that might ensue. In truth, it cannot; the uncertainties are usually such that, while the analyst may aim to produce facts and proofs, the results are merely evidence and arguments. But analysis can almost always eliminate the really bad alternatives, leaving the decision maker a choice from among the relatively good ones.

Assistance to a decision maker can take a number of forms. For him, to decide is not enough; decisions must be accepted by other decision makers (a group that often includes those who must change as a consequence of the decision), and then be carried out. Systems analysis can help with both acceptance and implementation.

So far in the history of their subject, systems analysts have mostly limited their help to decisionmakers and the public by trying to see that better actions are taken by discovering what these better actions might be, but sometimes, unfortunately, with "better" defined solely according to the analysts' standards; they have seldom tried to help by marshaling arguments and using systems analysis as a tool of advocacy for the better actions. However, some of the most significant uses of systems analysis may be obscured if we regard it simply as a means of producing information for the intellectual task of problem solving. Certainly, this is its most important function, but, particularly in the political arena, problem solving requires more than discovery of a good solution; it requires winning acceptance for this solution and seeing that its effect is not nullified during the implementation process. Systems analysis can be used to convert perceived problems into political issues, to legitimize decisions, and to assemble support for proposed actions.

Analysis before a decision, even though it is almost never adequate to prescribe the decision, has a number of virtues. Among other things, it:

- Introduces a certain amount of objectivity into a subjective process;
- Can take uncertainty into account explicitly;
- Considers specific issues in larger contexts and determines interactions and side effects;
- Tends to shift debate from means to consequences;

- May reveal unanticipated consequences of policies and actions;
- Evaluates and compares alternatives in a consistent and systematic way;
- May provide insight into issues and suggest better alternatives;
- Reveals some of the linkages between objectives and feasible results.

Analysis has a certain authority. As Harvey Brooks (1976) puts it:

> The usefulness of systems analysis depends on the fact that its conclusions purport to be based on a set of neutral principles that command a wider consensus than those conclusions themselves would be likely to command without a demonstration that they are logically deducible from such principles. In this sense, policy or systems analyses perform a function with respect to political-technological decisions similar to that performed by a judicial process with respect to conflicts between individuals. A court decision is accepted by the disputing parties largely because it is based on a set of rules both parties accept applied through a procedure which both parties are prepared, before knowing its outcome, to accept as unbiased.

This authority can be put to many good uses. However, it must also be admitted that there are potential ways to misuse systems analysis as well. For instance, in addition to what the analyst may be told is the purpose, a decision maker may commission a study to provide himself with an "expert" facade for promoting his preconceived ideas or policies, an excuse for inaction and delay, or a shield for his actions that is hard to penetrate or challenge without rival analysis. Too, systems analysis may be misunderstood or produce misleading information, for example, by implying unwarranted degrees of confidence in oversimplified or partial results, or overemphasizing the readily treated (but often less important) quantitative aspects of problems while neglecting other attributes and values that are difficult to quantify and thus can be treated only by judgment. Canons of good practice enjoin the analyst from such misuses.

On the other hand, systems analysis for an organization or a society, done properly and properly understood and acted upon, can, in the opinion of most of those who have had some experience with it, bring the following beneficial consequences:

• Policies and actions that may more effectively (and/or efficiently) achieve the decision makers' desired objectives, with few undesirable side effects;

• Explicit consideration of assumptions, uncertainties, costs, consequences, spillovers, etc.:

• An objective framework and common base for part of the political process, a separation and clarification of objective components;

• Improved understanding of the issues and hence better "intuition" on the part of the decision makers;

• A logical framework for considering and setting policy goals;

• Improved managerial capabilities for planning and administration;

• A better means—economic, political, organizational, technological—for setting and effecting national, regional, or institutional objectives;

• New options, new goals, and new horizons that expand people's perceptions of what might be and that offer them the chance of improving their lives.

There are also adverse features that may follow from dependence on analytic methods. To minimize them, specific consideration must be given in systems analysis to the possibility that they may occur. Here are examples:

• Delays in making decisions;

• Increased centralization and concentration of decision making in top-level staff;

• Increased dependence on complex processes (for example, computerized information systems) that require continuing attention by expensive talent in order to work well;

• Elimination of inefficiency and redundancy that, while costly, may have served to meet unexpected contingencies, resulting in greater dependence on processes and policies that, while finely tuned to specific situations, may not be robust or reliable under changing or "dirty" conditions.

However,adverse consequences of these types are results of defective analysis or of the improper use of analysis—and good analysts will see to it that such pitfalls are avoided. If, for instance, redundancy in a system is of value in spite of its additional cost, the analysis, when done properly, should show this to be the case.

Systems analysis, like every other human endeavor, has its limitations. One of these is that it is of necessity incomplete; time, money, and other costs place severe limitations on how thoroughly any topic can be studied, but even without such restrictions, the analysis is incomplete. It simply cannot treat all considerations that may be relevant. Problems tend to proliferate, as mentioned earlier, and, to quote E.S. Quade (1975), an experienced systems analyst, there is no "stage at which we know all there is to know. We may stop because the return for effort is becoming vanishingly small, but there still will remain research that could be done."

Since systems analysts are human, and since science presents us at best with only partial knowledge of the world's phenomena, it is too much to expect that systems analysis can make recommendations that are rigidly objective,totally free from arbitrary judgment, and completely based on science, even about issues that are scientific in character. Faced with the problem of giving advice about such things as the effects on stratospheric oxygen of the nitric oxide in the exhaust of supersonic transports, or the health hazards of low-level radiation, or the risk of failure of the emergency core-cooling system of a reactor, systems analysis is not in a position to provide unambiguous answers. This is due in part the failures of today's science. But consider environmental standards. They have significant distributional aspects, for they affect people in different locations and walks of life in different ways, and questions of distributional equity cannot be settled on purely scientific principles.

Since it is the nature of systems analysis to explore the difficult problems on the frontiers of our understanding of the workings of sociotechnical systems, the history of the subject (as Chapter 2 brings out) has been strewn with difficulties, and failures have occurred as well as successes. Thus, systems analysis is not without its critics; they say that it is too complicated, that analysts are more interested in research than in solving real world problems, that there is too much emphasis on cost, that it is waste of money. Undoubtedly the results have sometimes been unusable and misleading; Hoos (1972) cites a number of examples. More fundamental criticisms have been expressed by Dror (1971), Majone (1977), Tribe (1972), and Lynn (1980). Tribe's criticisms, as stated in Rowen (1976), are that policy analysis (systems analysis in our terms):

(1) Concentrates on tangible, quantifiable factors and ignores or depreciates the importance of intangible, unquantifiable ones;

(2) Leaves out of consideration altogether certain "fragile" values—e.g., ecological or aesthetic concerns;

(3) Focuses on results and, in its search for common measures, ignores both the processes by which preferences and decisions are formed and significant qualitative differences among outcomes;

(4) Tends to operate within limits set by the interests and values of the clients;

(5) In the effort to be objective, employs deceptively neutral and detached language in dealing with intensely moral issues;

(6) Artificially separates facts from values; and

(7) Tends to overlook distributional objectives in favor of efficiency objectives.

However, these criticisms of some cases of past practice must not be viewed as intrinsics of systems analysis; rather, they are pitfalls to be avoided in practicing the art of systems analysis.

There are, of course, other means than systems analysis for helping a decision maker.

The policy advisor is the traditional source of advice. He may be a generalist experienced in political matters or a specialist, an expert in economics, physics, sociology, or another field. Such advisors are often well informed on the issues and the decision makers' preferences, but unless their assumptions and chain of logic are made explicit so that others can use the information and reasoning to form their own considered opinion, biases and omissions may go undetected. The opinion of the advisor can, in fact, be very helpful, particularly if it results from a carefully reasoned and impartial examination of the problem situation with due allowance for the costs and risks. In other words, if he bases his advice on whatever analysis he can do with the resources and time available to him, the advice is likely to be superior to what he might give based on intuition alone. However, such an advisor is limited to what he can do by himself.

Committees are a second alternative, in the belief that an advisor's knowledge and opinions are likely to be more valuable if they can be joined with the knowledge and opinions of other advisors and experts to reach a consensus. Unfortunately, the findings of many committees are obtained by bargaining rather than by reasoning, and, on a committee, personality and prestige often outrank logic.

A third alternative is "muddling through," a sort of trial-and-error process in which naturally occurring feedback from what actually happens is supplemented by limited analysis. Administrators and policy makers have long gone about making decisions in this way—using analysis on parts of their problem, taking remedial steps rather than innovative ones, moving away from ills rather than toward definite objectives, seeking vague goals sequentially.

The argument that systems analysis, even though it may be incomplete, is to be preferred to the intuition of an expert, or to bargaining by a committee, is based on the belief that the results will be better, i.e., that the decision maker will prefer the results he gets from analysis to what he would have done without the analysis. We cannot prove that analysis will produce better results; sensible decisions are clearly possible without systems analysis, for many have been made. Also, it is clear that the practice of systems analysis involves a cost, and the cost of analysis may be greater than the cost of error. However, the lessons of the history of systems analysis, and the magnitudes of the problems the world faces with it sociotechnical systems, argue that, properly carried out and suitably applied, systems analysis can make important—even essential--contributions to solving these problems.

9. THE CRAFT OF ANALYSIS

The difficulty in telling a would-be practitioner of systems analysis how to practice, as we try to do in this *Handbook*, is that systems analysis, like scientific research and engineering practice, is to a large extent a craft activity in which a skilled person draws upon the knowledge and tools of many different sciences and technologies to weave together a product responsive to the needs of the eventual users. Unlike much of engineering, the work of the systems analyst (and of the scientist as well) is guided and controlled by methods that are mainly informal, *ad hoc*, and tacit, rather than formal, public, and explicit. It is desirable for any presentation of the methods of systems analysis to make these guiding ideas as explicit as possible, but this may be impossible to do in written form alone. Case studies that illustrate how an experienced analyst goes about his craft may help, but such studies are not easily formulated and are no substitute for on-the-job training in an art or craft.

The way to carry out a systems analysis of a given problem or issue cannot be described by an unquestioned set of rules. There is no set of steps for the analyst to follow by the numbers that will lead the decisionmakers without exception to the correct decision. The primary decision—what action to take—is the responsibility of the decisionmakers. The path to the primary decision, however, depends on what White (1972) calls a host of "secondary decisions" by the analyst, made more or less subjectively, based on intuition and experience. These secondary decisions include the many simplifying assumptions that must be made if a complex issue is to be made tractable: the choice of what aspects of the primary problem to leave out, the selection of an analytic approach, the extent of the sensitivity testing, and many others. Proficiency in making these methodological and procedural decisions is part of the *craft* of systems analysis, as discussed at length in Chapter 10. A detailed examination of the work sketched in the examples at the beginning of this chapter would show many examples of the application of craft knowledge. For example, several successful simplifications were critical in enabling the models in the blood-supply example to yield easily computable results.

In systems analysis, artistry and craftmanship are nowhere more in demand than during model building. Often, in constructing a model, the systems analyst may find himself at the frontier of the state of the art. He then may have to rely heavily on his judgment and intuition about whatever expertise may be available, rather than on solid (nonexistent) theory. The demands of problems in the real world require that, even if the current state of science provides no theory, well-established or otherwise, of the phenomena to be dealt with, the analyst (as Helmer 1966 states) "must nevertheless construct a model as best he can, where both the structure of the model and its numerical inputs have an ad hoc quality, representing merely the best insight and information that the analyst happens to have available. As further insights accrue and more experimental data become available, the (systems) analyst has to be prepared to discard his first model and replace it with an improved one. The tentative procedure, dictated by pragmatic considerations, is thus essentially one of successive approximation." A good craftsman makes this process converge to a useful model within the relevant time period.

10. CONCLUSION

The notion has been around for a long time that numbers and logic ought, if not to rule the world, at least, to play a major role in that rule. Until recently, however, only a few philosophers have had much faith that this might actually come to pass. For the rest of us, quantitative scientific analysis admittedly had a place in engineering, and in science itself, but for determining decisions and policy in the world of affairs, it had very limited applications; *that* world would continue to be governed by tradition, judgment, intuition. Wisdom, insight, perseverance, and politics made our leaders great, not calculation.

Systems analysis represents a considerable challenge to this point of view. It offers a way to bring scientists, including those in economics and the behavioral disciplines, and their knowledge and methods, into domains where decisions have been almost the exclusive prerogative of politicians, lawyers, and entrepreneurs. To date systems analysis has found many applications, with results at least promising enough to generate considerable clamor for more—although not without some criticism.

Systems analysis, as we have tried to make clear, is not a method or technique; nor is it a fixed set of techniques; but rather a concept, or way of looking at a problem and bringing scientific knowledge and thought to bear on it. That is, it is a way to investigate how to best aid a decision or policy maker faced with complex problems of choice under uncertainty, a practical philosophy for carrying out decision-oriented interdisciplinary research, and a perspective on the proper use of the available tools. We have also in this chapter discussed the type of problem with which systems analysis can deal, given an idea of its value for policy makers and the public, and contrasted it with alternative sources of advice.

What this chapter has *not* done is provide advice on how to to carry out a systems study, how to overcome or avoid the problems and difficulties so that desired outcomes are attained. Except for the more technical and mathematical tools, which are left for a later volume, this advice is contained in the remaining chapters of this volume.

One more point should be made here. For success, systems analysis requires not only a competent producer but also a knowledgeable and sophisticated consumer or user. To get full benefit, the user needs to understand the character of policy-level research; he must, for instance, understand that finding out what needs to be studied is a crucial part of the process of applying systems analysis to almost every problem. Consequently, the chapters in this volume that follow are written both for the producer and the user of systems analysis.

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