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FOREWORD

This brief introductory paper was written as a contribution to Roger Levien and S. Radhakrishna, editors, A Systems Approach to the Problems of Developing Countries, to be published in India in 1981.

After this essay and two others dealing with the questions of how systems analysis can help with problems in developing countries, the book will discuss some 15 examples of such work.

This paper is based on a talk given at a workshop on "A systems approach to the problems of developing countries" that took place at IIASA 2-4 September 1980; it was sponsored jointly by IIASA, the Committee on Science and Technology in Developing Countries, and the United Nations Educational, Scientific, and Cultural Organization.

WHAT IS SYSTEMS ANALYSIS?

Hugh J. Miser

Introduction. The well-informed citizen of our time is concerned about the problems of society, and he feels that, somehow or other, science and technology should aid in solving them. On the one hand, his view of science is probably conditioned by the artifacts that technology has produced--air and space craft, automobiles, radio and television, electrical appliances, pocket computers, large technical enterprises and their products; on the other, he is also aware of the unhappy effects of some of this technology--air and water pollution, environmental threats from pesticides and fertilizers, chemical carcinogens. This new technology has been accompanied by marked changes in social and economic systems, and they have been accompanied by undesirable dislocations and unfortunate effects.

In the face of this conflicting picture of the desirable and the undesirable, society expects science and technology to play a constructive role in improving the lot of mankind. How can this expectation be met?

To address this question, let us first distinguish somewhat crudely three classes of problems:

1. Those dominated by their scientific and technological components, and hence those for which we may reasonably expect

science and technology to play leading roles in solving--such as finding a cure for cancer, or developing new means of transportation and communication.

2. Those primarily systemic in character, with men involved with machines or in a highly structured environment in complicated operations (such as factories, transportation systems, hospitals, government service organizations, government ministries, or social systems).

3. Those not belonging to either of the first two classes, including problems dominated by politics, morality, religion, or aesthetics, or problems beyond the potential reach of science and technology (such as climatic changes over the next million years, or the effects over the next ten millennia of low-level radiation hazards).

The least discussed and least appreciated of these classes--especially among scientists and technologists--is the second, the problems arising from the operations of the social systems that incorporate the artifacts of our technology or the organized structures of our society. Such social systems are all around us; indeed, we participate in many: we involve ourselves with the transportation system daily; we depend on the atmospheric system for life while we also use it as a place to dump transportation, heating, and energy-generation effluents; many of us live in cities; and when ill we call on the health-care system for help. Because we are parts of these systems, we must share in the measures taken to improve their operations--and we will probably want to share in both the activities leading to their improvement and the choices for change that will be made.

It is these systemic problems that systems analysis addresses its attention to, in cooperation with others having interests in them and their solution.

<u>Properties of the systemic problems of society</u>. Why do these problems call for scientific activity and technological ingenuity? Why are the classical administrative, political,

and social arrangements not adequate to address these problems, as they always have been in the past? Some of the answers to these questions lie in the properties of many of these systemic problems; in each case, I could offer a relevant current example, but to save space I will leave the examples to the imagination of the reader:

- Exactly what happens is often not understood by the public and executives in positions capable of influencing the outcomes.

- The phenomena relating to a problem usually have not been observed carefully and measured systematically.

- Analyses of the available observations and measurements have usually not been carried out.

- Cause-and-effect relations are often not known with any certainty.

- An executive faced with a problem usually has some sort of mental image of the phenomena producing his problem. If this image is constructed from reliable evidence, then it serves as a theory--what some scientists call a "model"--for the phenomena, and problem solutions making use of what it tells the executive may well alleviate the problem. However, such a verified theory or model on which to base reliable predictive perceptions, and therefore potential problem solutions, often does not exist.

- An operating process can usually be characterized usefully by simple models or key parameter values, but reliable information of this sort is surprisingly often absent, or very difficult to estimate reliably for a social system.

- Surprising as it may seem, there are important systemic problem areas for which a systematic scientific and technical literature is not available.

- The effects of new programs, or changes in old ones, often cannot be predicted, on the basis of existing knowledge, with any reasonable certainty.

- For many areas of public need, realistic preferred program alternatives have not been developed, together with estimates of their costs and benefits.

- Criteria for selecting such preferred programs or courses of action have usually not been well developed.

- It is commonplace for the true natures of the problems and the objectives of proposed solutions to remain unclear, even after considerable public debate and attention has been paid to them.

- The responsibilities with respect to society's systemic problems are almost invariably widely distributed.

- The widely held public view of many problems and potential solutions is at variance with the facts.

- Partial, mistaken, or unproven solutions to public problems are often advocated heatedly on less-than-adequate bases.

- The problems and the phenomena that cause them are frequently so diffuse in time and space as to defy comprehensive observation, or even easy systematic sample viewing, by those with relevant responsibilities.

- The problem contexts are frequently dominated--or at least significantly influenced--by outmoded, archaic, or even counterproductive practices, concepts, equipment, training, or systems.

- Results of experimentation or careful inquiry often deviate from commonly held views and prejudices.

- In social systems without an associated science based on careful observation and verified theory, problems come to be regarded as predominantly for "experienced experts" or political debate to solve, and consequently outside the realm of scientific inquiry or technical treatment--with resulting suboptimal, or even harmful, practices and policies.

- Solutions to problems often call for widespread changes in practicies, laws, jurisdictions, equipment, personnel, and systems--and such changes are impossible to achieve without compelling evidence that they are needed.

- The underlying problem context often involves so many factors and the phenomena associated with them, so many attributes of public interest, so many possible options and their consequences, and so many criteria bearing on possible choices that the human mind is incapable of carrying all of the needed detail simultaneously.

The aim of this listing of the properties of society's systemic problems is to give substance to the belief that, as a rule, the behavior of society's systems is too complicated to make intuitive expectation a reliable guide to understanding, whether the intuition be that of citizen or scientist; therefore:

- The phenomena associated with the problems of our social operating systems need careful observation, measurement, and characterization by models (or theories) with demonstrated predictive value.

- The operating and policy problems of these systems need to have their solutions carefully engineered on the basis of such knowledge, to the end that the programs adopted will have predictable results at acceptable costs, and thus reach the social goals at which they are aimed.

The aim of systems analysis is to meet these needs.

Systems analysis, or the systems approach. What we have argued so far is that the functions of society involve structures that can be thought of as systems combining people and the natural environment with various products of man and his technology, and that such complex systems abound in modern society and exhibit many problems that we would like to solve. The question then is: How can the approach of science help solve problems in this complex setting?

The key fact is that such complex systems and their elements, while exhibiting many forms of complicated behavior, sometimes also contain regularities that can be discerned by scientific scrutiny. Indeed, scientific inquiry has yielded much knowledge about such regularities in the systems that it has examined. Where this is the case, the door is open to constructing a scientific body of knowledge and using it as the basis for problem solving.

Thus, many problems arising in operating social 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; it brings to bear the knowledge and methods of modern science and technology, in combination with concepts of social goals and values, elements of judgment and skill, and appropriate consideration of the larger contexts and uncertainties that inevitably attend such problems.

Thus, the central purpose of systems analysis is to help to solve the problems of complex systems by generating information and marshalling evidence bearing on these problems, and, in particular, on possible actions that may be suggested to alleviate them.

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 possible courses of action, the information needed, the accompanying constraints and uncertainties, and the positions and responsibilities of the persons who may use its results. In a rare case, a problem may fall within the sphere of responsibility of a single policy maker; however, it is far more usual for the relevant responsibilities to be diffused among many persons, often with significant portions of the problem lying outside existing authorities.

While applied systems analyses may exhibit as much variation as the problems that prompt them, it is nevertheless useful to list a number of things that a prospective user of such work can expect to find in it. Applied systems analyses:

- Marshal both the evidence relating to the problem and the scientific knowledge bearing on it, when necessary gathering new evidence and developing new knowledge.

- Examine critically the social purposes--both those of persons and institutions--relating to the problem.

- Explore alternative ways of achieving these purposes, often including designing or inventing new possibilities.

- Reconsider the problems in the light of the knowledge accumulating during the analyses.

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

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

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

- Assist in following up the actions chosen.

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

However, because these steps are listed here in order, it would be a mistake to infer that they take place in this order in a systems-analysis study. Rather, there is almost always a great deal of recycling of ideas and analysis; for example, the impacts of the chosen courses of action may dictate reconsidering the social purposes, the analysis of the chosen alternatives may generate new and more interesting ones for consideration, and so on. Nor do all systems analyses carry out all of the steps; the user may need only some of them carried out. Since the world does not stand still while the work is going on, its changes may dictate major changes in content and approach, or, since user representatives must work with the analysis team throughout if the work is to be effective, early results may get translated into action or policy quickly. All of these influences may change the pattern of the work.

From a professional point of view, what sort of work does the systems analyst do? We can expect him to: observe and describe the behavior of complex systems; build models, where they are needed, to explain these observations, and test the extent of their validity for the purposes of his analysis; use these models, in combination with other knowledge and constructs, to deduce and synthesize descriptions of the behavior of important segments of the systems under study; use technical ingenuity and design synthesis to devise programs or courses of action; devise methods of generating comparisons of the alternative courses of action; develop ways of communicating the results effectively, not only to other systems analysts, but also to persons in a variety of other communities of interest and responsibility; find ways of helping effectively in the administrative activities of implementation; and devise procedures and standards for evaluating the results of implemented courses of action. Throughout the work, the analyst must be in close contact with his client.

To summarize, the central goal of the systems analyst, based on his understanding of the systems he has been studying, is to bring his results to bear on the functions of complex operating systems in society with a view to improving them; he helps those with relevant interests and responsibilities to change these functions beneficently. His analysis activities are aimed at assuring himself and others, to the extent possible, that the changes will have desired results.

<u>Problems that have been treated by the systems approach</u>. Since most of the rest of this book is devoted to actual problems to which the systems approach has been or can be directed, there is no need to provide an extended discussion of examples here. However, it may be useful to suggest the wide spread of

actual and potential uses of systems analysis, and to list some sources of the extensive literature.

In the context of developing countries, systems analysis has been used on problems like these: routing and scheduling the buses in Baroda, India; developing the water and power uses in the Indus Basin; contributing to the economic development planning in Korea; planning agricultural policy in Mexico. More generally, case descriptions are available in the literature on many industrial planning and operating problems (such as capacity expansion, sequencing of tasks, and maintenance), energy planning (investment and system expansion), transportation (control of urban traffic and airline booking), water resources (river-basin utilization and rural water supply), irrigation (feasibility and investment evaluation), agriculture (choosing the optimal animal population and managing water in poultry processing), health-care delivery (emergency admissions and scheduling surgery), urban planning and management (developing new communities and making decisions about urban services), education (design and planning), and tourism (investment allocation)--and many more.

All of these examples are taken from a booklet prepared by a committee under the chairmanship of Prof. Philip M. Morse, one of the pioneers of operations research and systems analysis; this source provides, not only further discussion of these examples and an extensive bibliography of literature relevant to the problems of developing nations, but also information and wise counsel on organizing systems-analysis activities, staffing them, training workers in this field, and getting help in these matters (1).

For another introductory overview of systems analysis, see Miser (2), which also provides a comprehensive overview of introductory literature in operations research and systems analysis. A Handbook of Systems Analysis is being prepared at the International Institute for Applied Systems Analysis in Laxenburg, Austria, that will provide an overview of this field (3).

Conclusion. Since most of the problems that systems-analysis workers deal with involve diverse factors, it is usually the case that classical disciplines such as economics, physics, biology, and so on provide important knowledge relating to their work. Thus, it is common--indeed, almost universal--for such teams to be multidisciplinary in their composition, a consequence of the problem orientations of the teams.

It is also universal that the problems are ones for which others have responsibilities and interests, which produces close working relations between the scientists and these other persons.

Thus, in its highest and most effective form, systems analysis joins science and society in the search for improvements in the common lot.

References

1. Ad Hoc Panel (Philip M. Morse, Chairman) of the Board on Science and Technology for International Development, Systems Analysis and Operations Research: A Tool for Policy and Program Planning for Developing Countries, Commission on International Relations, National Academy of Sciences--National Research Council, 2101 Constitution Avenue, Washington, D.C. 20418, USA. Single copies available free to institutionally affiliated recipients.

2. Hugh J. Miser, Operations Research and Systems Analysis, Science, vol. 209 (1980), 4 July 1980, pp. 139-146.

3. Edward S. Quade and Hugh J. Miser, editors, Handbook of Systems Analysis, to be issued. Draft chapters are available from the International Institute for Applied Systems Analysis, 2361 Laxenburg, Austria.