OPERATIONS RESEARCH METHODS: A GENERAL APPROACH IN PRIMARY HEALTH CARE

Stewart N. Blumenfeld

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Operations Research Issues: Community Organization
Operations Research Methods: Cost-Effectiveness Analysis

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PREFACE

Primary Health Care Operations Research (PRICOR) is a project of the Center for Human Services and is funded by the United States Agency for International Development (AID) under a cooperative agreement (AID/DSPE-5920-A-00-1048-00). The Center for Human Services is a nonprofit, development services organization specializing in the design and management of programs that address the basic needs of people in developing countries and the United States. PRICOR's objective is to promote operations research as a tool to help program managers and policymakers find solutions to problems they encounter in designing and operating primary health care (PHC) programs.

This project's activities include: funding and monitoring country studies; sponsoring workshops and conferences; conducting methodological and comparative studies; and disseminating the findings of sponsored research. PRICOR is particularly interested in research designed to overcome problems that limit the expansion of essential PHC services to high-risk populations in rural and peri-urban communities. Consequently, PRICOR has concentrated on operations research to find solutions to problems in four priority areas:

- Community health workers
- Community-based commodity distribution
- Community financing
- Community organization

Operations research provides a systematic approach to problemsolving. In operations research, rather than relying on the costly process of trial-and-error, a well-defined plan of analysis is used to select the best of several possible alternatives. A specific operational problem is first defined and analyzed. Alternative solutions are developed and evaluated to identify those that are most appropriate and feasible. Recommendations are then made for testing, or in some cases directly implementing, the best solution(s).

This is one in a series of five monographs on operations research that was prepared by PRICOR staff and consultants for researchers in the developing world who are interested in learning more about this approach and applying it to their own primary health care programs. The five monographs in the series are:

- Methodology Papers

  1. Operations Research Methods: A General Approach in Primary Health Care
  2. Operations Research Methods: Cost-Effectiveness Analysis

- Issue Papers

  1. Operations Research Issues: Community Financing
  2. Operations Research Issues: Community Health Workers
  3. Operations Research Issues: Community Organization

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- Morris Schaefer, D.P.A. — School of Public Health, University of North Carolina
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All were kind enough to submit exceptionally detailed suggestions on both style and substance and many of these have been incorporated into the paper as it now stands. Many ideas gleaned from discussions with PRICOR colleagues over the period this paper was in preparation also are presented here. The author is grateful to members of the PRICOR support staff, Frances Gallagher and Esther Peckam, for the great deal of assistance provided in preparation of drafts and final product, and to Elizabeth Scullin for editorial assistance.

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ABBREVIATIONS USED IN TEXT

AID	Agency for International Development
CBA	Cost-Benefit Analysis
CEA	Cost-Effectiveness Analysis
CHW	Community Health Worker
KAP	Knowledge, Attitudes, and Practices
OR	Operations Research
ORS	Oral Rehydration Salts
ORT	Oral Rehydration Therapy
PHC	Primary Health Care
PRICOR	Primary Health Care Operations Research

INTRODUCTION

Primary health care is gaining acceptance as a strategy for bringing basic health services to all people in developing nations who do not have access to such services at this time. Primary health care programs can have a significant impact on health by focusing on a limited number of health problems that are preventable by means of simple, relatively low-cost interventions.

Diarrhea, respiratory infections, malnutrition, and contagious diseases are among the most serious health problems in developing countries. They result in high rates of infant, child, and maternal mortality and morbidity, particularly in rural areas and in the surroundings of urban centers, where organized health services are most limited. Ironically, much of this suffering is avoidable, because a few primary health care interventions could dramatically reduce these problems if ways could be found to reach the target populations--particularly women and children--with such needed primary health care services as immunizations, oral rehydration therapy (ORT), growth monitoring, family planning, malaria prophylaxis, water supply, environmental sanitation, and antepartum and perinatal care.

In 1978, the International Conference on Primary Health Care was convened at Alma-Ata in the Soviet Union. At this historic event attended by representatives of 134 nations, primary health care was endorsed as a strategy for making fundamental health services universally accessible to the world's population. The Declaration of Alma-Ata defines primary health care as:

> . . . essential health care based on practical, scientifically sound and socially acceptable methods and technology made universally accessible to individuals and families in the community through their full participation and at a cost that the community and country can afford. . . . [Primary health care] addresses the main health problems in the community, providing promotive, preventive, curative and rehabilitative services accordingly . . . [it] includes at least: education concerning prevailing health problems and the methods of preventing and controlling them; promotion of food supply and proper nutrition; an adequate supply of safe water and basic sanitation; maternal and child health care, including family planning; immunization against major infectious diseases; prevention and control of locally endemic diseases; appropriate treatment of common diseases and injuries; and provision of essential drugs.(1)

Among those organizations helping to find ways to achieve this goal is the Agency for International Development, which has supported numerous primary health care projects around the world. These projects, extensively documented in a recent American Public Health Association publication, have demonstrated the efficacy of primary health care in reducing premature mortality and excess morbidity.(2)

The Agency for International Development has been particularly interested in finding ways to expand coverage of mothers and children in rural and peri-urban areas with such essential primary health care services as immunizations and oral rehydration therapy, among others. However, AID and other international donors have learned from experience that meeting this objective is not a simple matter.

Role of Operations Research in Primary Health Care

A number of operational issues need to be resolved before primary health care can become universally available. For example, the Alma-Ata Conference report noted that:

> Enough is already known about primary health care for much of it to be put into practice immediately. However, much still needs to be learned about its application under local conditions, and during its operation, control and evaluation problems will arise which will require research. These may be related to such questions as the organization of primary health care within communities and of supporting services; the mobilization of community support and participation; the best ways of applying (existing and appropriate) technology . . . the planning for and training of community health workers, their supervision, their remuneration and their career structure; and methods of financing primary health care.(3)

Recognizing the importance of research into the operation of primary health care delivery, the AID Office of Health funded PRICOR to help primary health care program managers and policymakers find solutions to such problems through operations research. PRICOR has defined operations research as a problemsolving process consisting of three phases:

1. Systematic analysis of the operational problem;
2. Application of the most appropriate analytical methods to identify the best solution(s) to that problem; and
3. Validation of the solutions(s).

Although operations research has not yet been widely used as an analytical and decisionmaking tool to improve health services in developing countries, it can be applied to examine a number of issues pertinent to primary health care service delivery.

For example, operations research can be applied to examine the advantages and disadvantages of different approaches to involving the community in the organization of a primary health care program, to assess existing organizations (e.g., farmers' cooperatives, development committees, and churches) to determine which would be most effective in helping to expand primary health care coverage, or to study community involvement in primary health care and identify ways to improve it.

This paper is aimed at managers and researchers in developing countries who see a need to bring a systematic decisionmaking approach to bear on problems of health services delivery. Its specific objectives are:

1. To describe in some detail the general operations research approach outlined above; and

2. To describe a number of operations research techniques which can be used by the nonspecialist in carrying out problem analysis and solution identification.

NOTES

1. "Declaration of Alma-Ata, "Primary Health Care, Report of the International Conference on Primary Health Care, Alma-Ata, USSR, 6-12 September 1978, jointly sponsored by WHO and UNICEF (Geneva: WHO, 1978), pp. 3-4.

2. Primary Health Care: Progress and Problems, An Analysis of 52 AID-Assisted Projects (Washington, DC: APHA, 1982).

3. WHO and UNICEF, Alma-Ata 1978, op. cit., pp. 71-72.

CHAPTER I

OPERATIONS RESEARCH AND PROBLEMSOLVING

CHAPTER I. OPERATIONS RESEARCH AND PROBLEMSOLVING

Operations research (OR) was developed as a management technology during World War II. By the 1950's, analysts were applying some of the specific techniques of OR to problems in planning health services. In the last decade, the use of OR techniques in health services management has expanded greatly.

Nevertheless, many program managers still are unfamiliar with this decisionmaking approach to solving operational problems in the delivery of primary health care services. Moreover, judging from the available literature, operations research has rarely focused on primary health care needs in the developing countries. In addition, most of the research that has been done has employed techniques originally developed for industrial applications that require a certain degree of mathematical sophistication. Thus, the potential for using operations research technology at a less sophisticated level by nonspecialists has not been fully appreciated.

This paper introduces health care researchers and program managers to basic operations research concepts and techniques for solving particular problems in primary health care service delivery. It focuses on techniques that can be employed by the nonspecialist and provides references for further information on more complex techniques.

WHAT IS OPERATIONS RESEARCH?

Operations research is the application of analytic methods designed to help the decisionmaker choose between various courses of action available to accomplish specified objectives. The analysis is aimed at determining which course of action is most likely to achieve those objectives and to do so most effectively and efficiently when compared to other possibilities. Thus, operations research is a planning technology; it is future-oriented. This prospective analysis approach is a key characteristic of operations research. It is conducted through a series of steps which begins with an analysis of the problem at hand, proceeds to development of appropriate solutions based on carefully specified criteria, and (often, but not always) concludes with field testing those solutions before adopting them. In many respects, this general approach is largely a matter of formalizing the logical thought process that many people pursue in trying to make decisions.

OTHER APPROACHES TO PROBLEMSOLVING

Other approaches to solving problems include intuition, analogy, and trial and error.

Intuition

Intuition is figuratively at the opposite end of the spectrum from the highly systematic, carefully rationalized approach of operations research. It occurs largely at the subconscious level and follows a line of reasoning that the individual may not be able to describe fully to others. The advantage of the OR approach compared to intuition is that it helps ensure that all, or nearly all, the important factors that bear on a decision will be considered openly. Conducting problem analysis and solution development in the framework of a clear analytic model enables all to understand what objectives are being sought, what factors bearing on those objectives are under consideration, and how those factors are being valued as the decision is reached. Decisionmakers whose intuitive solutions usually seem to lead to desirable outcomes often are said to have "good judgment." However, by definition "judgment" implies a more deliberate process of

evaluating factors involved in reaching a decision. Thus, judgment lies somewhere between intuition and operations research, and is separated from the latter by its lesser use of a formalized process for evaluating the factors which bear on the decision.

An example of intuitive resolution of a primary health care problem might be a decision to require that those selected for training as community health workers be from the village in which they would practice. This may or may not be a valid criterion, but it is one often made rather routinely and without direct analysis of the problem.

Analogy

Analogy involves applying successful solutions of previous problems to a new problem that seems similar. The effectiveness of this approach is heavily dependent upon how closely the new situation matches the old. It is valid when the match is thought to be good on those factors that are most influential in determining the outcome of a particular decision. Analogy is the underlying basis for the decision, for example, to expand a pilot test into a full-scale implementation of some decision. Analogy might be used--in this case, perhaps with poor results--to design a training program for village health workers that is modeled on the pyramidal approach used in training higher level health workers.

Analogy can be expanded into operations analysis if objectives are explicitly stated and those factors that strongly indicate achievement of those objectives are evaluated.

Trial and Error

Trial and error consists of a series of experiments and evaluations in which successive cycles are expected to lead to an ever-improving outcome. Price-setting for community financing of health services is often approached this way, with an initial pricing structure established on the basis of intuition or analysis, and subsequent modifications expected to lead to some desired combination of service utilization and community-derived financial support. Although trial and error may eventually lead to the desired outcome, it may also prove to be very wasteful of such resources as money, staff time, and even good will. As noted, the operations research approach calls for a preliminary analysis before any solutions are taken to the field; this is expected to minimize false starts and badly conceived solutions.

Depending upon the planning situation, all three of these methodologies--intuition, analogy, and trial and error--are used to some degree in varying proportions. One important purpose of this paper, in addition to showing some of the "how-to's" of operations research, is to help the planner understand how the OR approach, even as it consumes some resources itself (in terms of the time of project planning and management staff), contributes to overall planning efficiency in the long run by saving time and money. An additional benefit, in some cases, might be the maintenance of political and public support that might otherwise be lost as a result of false starts and unacceptable initial results in health care delivery programs.

OTHER RESEARCH METHODS

Some confusion exists with regard to the distinction between operations research and such other, more widely known, research techniques as descriptive characterization, evaluation, and systems analysis.

Three of the defining characteristics of operations research noted previously are: 1) prospective orientation; 2) decision-aiding purpose; and 3) systematic analysis to find a "best" solution. Although there may be a certain amount of arbitrariness in placing the

following types of research outside the bounds of operations research, generally these methods do not combine these three attributes.

Descriptive Characterization

One type of activity that is sometimes confused with operations research is the development of basic descriptive information on components and activities of the health care system. These are very important data which describe, for example, target populations (social, demographic, economic, and morbidity information), aspects of health-related behavior (service utilization patterns), and causal factors (knowledge and attitudes relating to treatment and prevention). Such data often constitute a vital input to an operations research exercise, but their production does not by itself constitute an analysis that helps select courses of action aimed at accomplishing specific objectives.

Evaluation

Although it is possible to view operations research as a form of evaluation, that is, as prospective evaluation of alternative courses of action, it is useful to retain a distinction between these two types of activities. Evaluation, as the term generally is used in the health services context, is intended to be either an assessment of how a health service system (or a part of it) currently is functioning or a retrospective look back at how well it achieved its objectives. Operations research, as noted earlier, is characterized by its prospective orientation and focus on action-oriented decisionmaking.

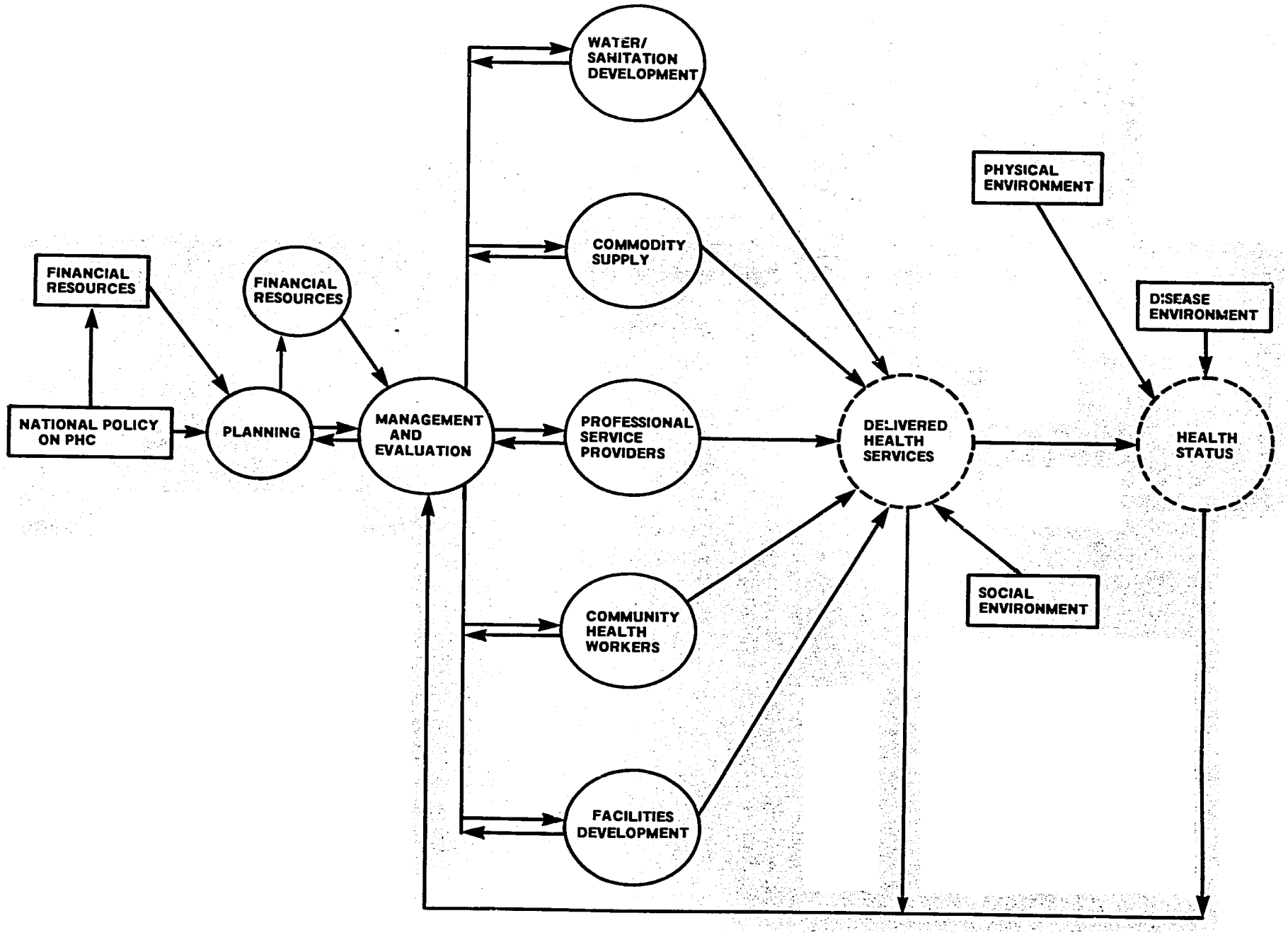
Evaluation aimed at assessing how well a system currently is functioning is called process or formative evaluation. It produces quantitative information on activities and use of the system.(1) Its purpose is to provide managers with an objective measure of how close a functioning system is coming to existing targets, such as services provided, coverage, and cost. The manager uses these data as the basis for making changes in operational procedures that will bring the system closer to meeting those targets. Such an evaluation is done while an operational activity is in progress.

Evaluation aimed at assessing how close a system came to achieving its objectives is called outcome or summative evaluation. It is designed to develop data that describe how close a project or program came to achieving its stated objectives.(2) This type of analysis is carried out at the end of a programmed intervention; that is, retrospectively. It can also be performed during a long-term program in order to allow time to correct a program that is not meeting its objectives, even though the process indicators have measured up to expectations. It is still a retrospective assessment, because it focuses on the question, what has happened so far?

Systems Analysis

A system is defined as a collection of parts, or components, that interact with one another to produce some effect that no one component could produce by itself. Systems analysis seeks to determine, for a given system, what those components are, how they interact with one another and with inputs to the system, and how the system is influenced by its external environment. One simple way to picture a system is as a machine of various parts that takes in one thing (called the input), processes it, and puts out a different thing (the output). The purpose of systems analysis is to aid in understanding why a system behaves the way it does in terms of how and why it converts a given set of inputs to particular outputs. The analyst expects that an understanding of this process enhances the opportunity to modify the system appropriately and obtain a more desirable output.

Figure 1-1.--First Model of a Primary Health Care System



Many systems, particularly social systems, consist of natural groupings of related components. These groupings are called subsystems. All the subsystems together constitute the system. It is not unusual in complex systems for subsystems to exist within subsystems. An example may help to illustrate this.

Figure 1-1 is a system model of an entire primary health care system. It shows major subsystems and how they relate to one another; an output, measured in terms of delivered health services (e.g., immunizations, health and nutrition education activities, and growth monitoring); and an outcome, measured in terms of health status. Such a model would be used either to help understand an existing system or as a planning tool to assist in a redesign of the system for greater effectiveness or efficiency.

Figure 1-2 shows a detailed elaboration of the community health workers (CHWs) subsystem within figure 1-1.

Some important terms, taken from the field of systems analysis, that will facilitate the discussion throughout the balance of this paper are defined below. (These may also be found in the glossary.) Resources that must be supplied to a system in order for it to function are called inputs. The products of a system are called its outputs. The activities that take place within the system as it converts inputs to outputs are called the process. A direct effect of those outputs is called an outcome. An indirect effect of one or more outcomes is called impact. A set of activities that utilizes part of a system to accomplish a particular group of objectives is called a program (or a project, if it is somewhat limited in scope and duration). To illustrate, in a program to reduce dehydration due to diarrhea by means of oral rehydration therapy using commercially produced salts, the salts would be an input, parental education by means of a health worker would be the process, children treated with oral rehydration therapy would be the output, and reduction in severe dehydration cases would be the outcome. Subsequent reduction in malnutrition rates would be a potential impact.

A distinction often is made between systems analysis and operations research based on the scope of the system of concern and the level of detail being investigated.(3) Systems analysis deals with the organization and function of entire systems at once, or at least large segments of systems, whereas operations research investigates the detailed process of one part of a system. Moreover, systems analysis is more descriptive in nature, intended to clarify why a system functions the way it does, whereas operations research is a future-oriented activity intended to answer the question of what course of action to take in order to achieve a specified objective. However, a systems analysis whose purpose is to determine how to modify a system for improved performance could be viewed as one of the tools of operations research.

Figure 1-3 diagrams the relationship between the development of information leading to the conclusion that an operational problem exists, selection of a means for determining what action to take, and the methodology employed by operations research. The following chapter details the OR approach to problemsolving.

NOTES

1. See K. Hennigan, et al., in R. Klein, et al., Evaluating the Impact of Nutrition and Health Programs (New York: Plenum Press, 1979).

2. Ibid.

3. N. Bailey, Mathematics, Statistics, and Systems for Health (New York: Wiley, 1977).

Figure 1-2.--Community Health Workers Subsystem

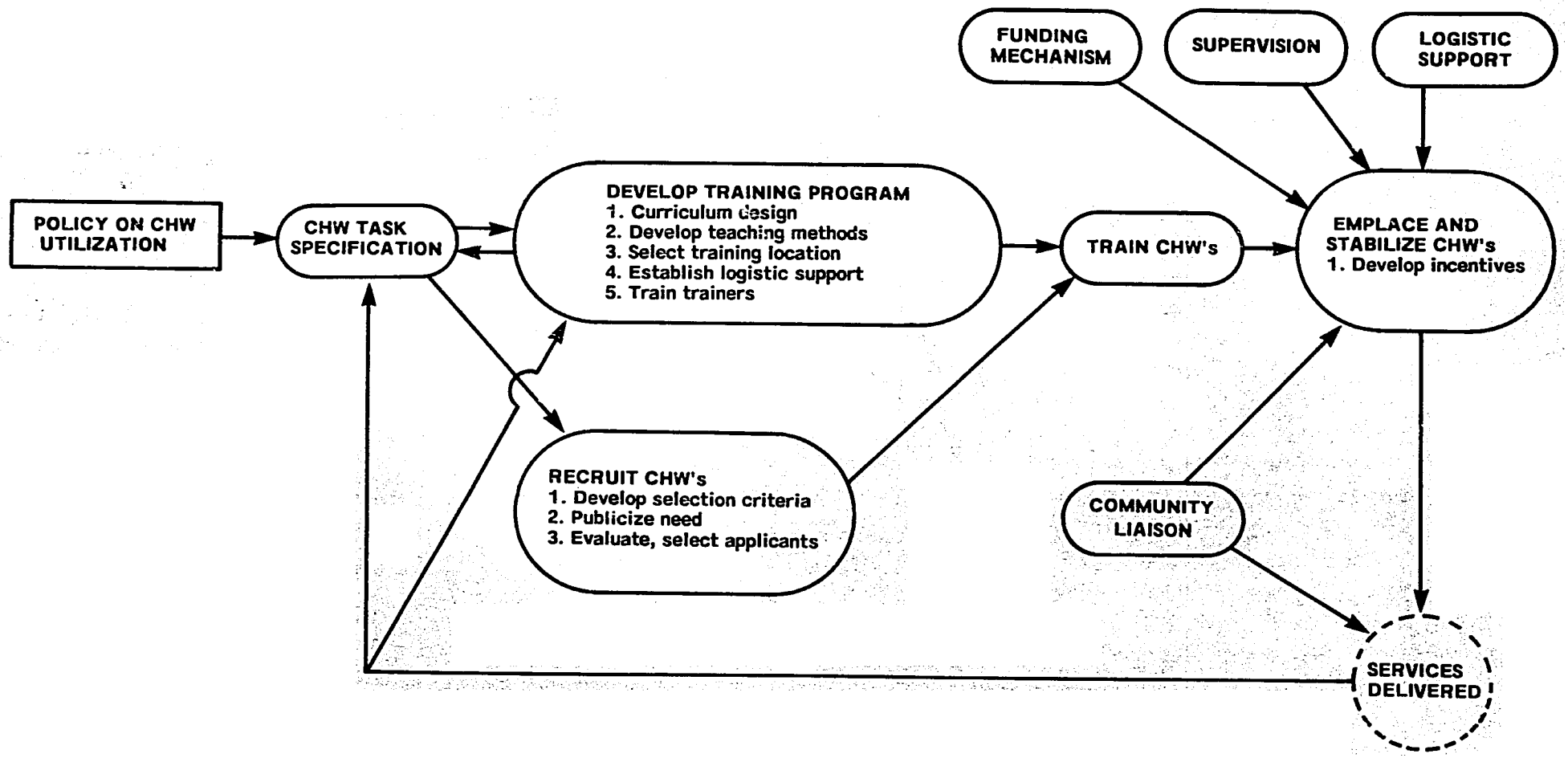
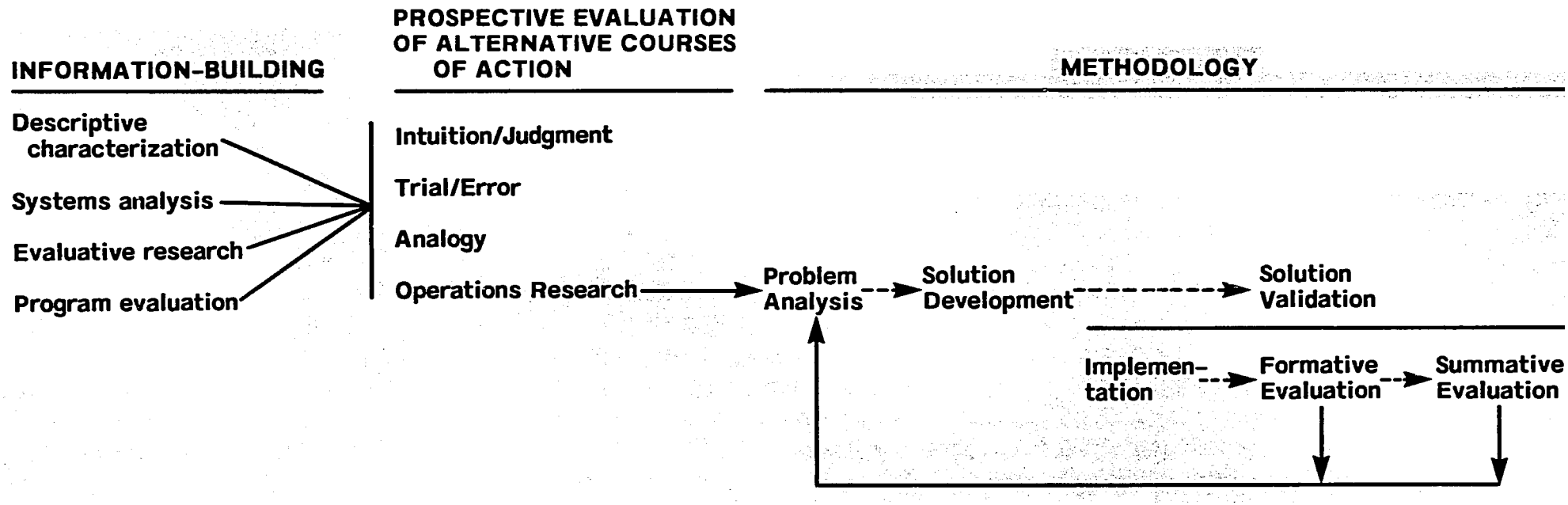


Figure 1-3.--Problemsolving Approaches



CHAPTER II

THE OPERATIONS RESEARCH APPROACH

CHAPTER II. THE OPERATIONS RESEARCH APPROACH

Application of the operations research approach comprises three phases: first, definition and analysis of the problem; second, development and assessment of potential solutions; and third, validation of the solution selected. Figure 2-1 shows these phases and the tasks involved in carrying them out.

Figure 2-1.--Summary of the Operations Research Approach

PHASE I: PROBLEM ANALYSIS

1. **Define the operational problem.**
2. **Analyze the problem and divide into smaller units.**
3. **Establish research priorities.**

PHASE II: SOLUTION DEVELOPMENT

1. **Specify solution objectives.**
2. **Specify decision variables and stipulate constraints on the solution.**
3. **Identify or construct an appropriate model for solution development.**
4. **Determine and obtain required data.**
5. **Develop solution using analytic model.**
6. **Perform sensitivity analysis.**

PHASE III: SOLUTION VALIDATION

1. **Design field test.**
2. **Implement field test.**
3. **Evaluate the proposed solution, modify if necessary.**
4. **Integrate the solution with the larger system.**

PHASE I: PROBLEM ANALYSIS

The three steps within phase I are, first, defining the operational problem(s); second, analyzing the problem and dividing it, if necessary, into a series of smaller sub-problems; and third, establishing research priorities within the group of sub-problems.

Defining the Operational Problem

Ideally, problem definition begins with discussion of the problem by the concerned decisionmakers, program managers, and analysts. If possible, these discussions should include service delivery staff and service recipients. The discussions are intended to obtain consensus with regard to the objectives of the subsystem, what are its components, what are its constraints (e.g., material, social, and political) and how firm these are, what additional resources might be obtainable, what are the expected outputs of the subsystem, what are the actual outputs, and why a gap exists.

It is important to obtain agreement on the objectives of the system. Objectives are specific, quantifiable milestones that mark progress toward achievement of a set of broader goals. In operational terms, objectives are the desired outputs of the system or subsystem under consideration.

Objectives may be specified either as the direct outputs of a system or the effects of those outputs, depending upon the needs of the decisionmaker. For example, if a decisionmaker is willing to assume that if enough community health workers are trained and stabilized (remain active at post for a specified period of time), so that 90 percent of the target population is within 5 kilometers of a health worker, there will be a decrease in morbidity and mortality, then the objective is training, emplacing, and stabilizing these workers. If, however, the decisionmaker will not make that assumption, then the objective must be stated in terms of reduction of morbidity and mortality. In any case, the objectives must be specified in quantifiable terms such as n CHWs trained and stabilized, x% of target children immunized, or y% reduction in severe dehydration due to diarrhea. The OR analyst must work with the system managers to ensure that objectives are specified in terms that will permit measurement of the effectiveness of the proposed solution to the problem.

Following a thorough discussion of the problem, the group should prepare a concise written statement describing the problem and the expected outcome of the OR task--but not, at this point, the OR methodology. All parties should concur in the statement so that it is clear to all what operational problem(s) will be attacked and why.

Analyzing the Problem and Dividing It into Smaller Units

After the operational problem has been defined, it should be analyzed and examined in detail. One of the best ways of doing this is by constructing a graphic system model such as that shown in figure 1-1.

The graphic model employed in an operations research task should be sufficiently detailed to show all the major components of the system or subsystem and how they relate to one another, particularly the interaction of staff at different levels in the system, flow of information, time sequence of activities, and movement of materials. The outputs of the system or subsystem should be shown, as well as required inputs. Actual numbers may be shown in the model to provide a realistic sense of magnitude. The nature, locus, and degree of influence of outside factors should also be shown. Factors that impinge on a system from outside, but are beyond the control of the system managers, are defined as "exogenous" to the system. It may be necessary to obtain specific information or data in order to complete the model, for example, data on who is currently using specific parts of the health care system and for what problems.

A graphic model greatly facilitates clear understanding of the problem and of the larger environment surrounding and influencing the system or subsystem. This kind of visualization is so useful that it often is developed in the course of the discussion outlined in the preceding step. It is possible to use techniques other than a system model in the analysis of a problem; for example, decision trees and interaction matrices. For most problems, however, nothing is as illuminating as seeing all the relevant components of the system on paper.

The first model should represent the system or subsystem as it actually is. If done in sufficient detail, it will enable the OR team to discover where the breakdown in the flow of activities, information, or materials is occurring and will provide much of the insight necessary to see where and what the operational problem is. Sometimes it is helpful to construct a second model, called a normative model, which depicts how the problematic

portion should look. Comparison of the two models helps to pinpoint the problem at this stage of the OR task and helps in the development of potential alternative solutions in a later stage.

As noted, figure 1-2 is an example of a graphic model of the community health worker subsystem shown as a component of the PHC delivery system of figure 1-1. The national policy on the use of CHWs is taken as exogenous to the system and is shown in a rectangle in the model; the activities shown in the ovals are endogenous, that is, they are composed of factors which are relatively controllable by the managers of the CHW subsystem. "Services Delivered," inside the dashed circle, is the output of the subsystem.

The model shown is not as rich in detail as it could be; any of the activities in the ovals could be elaborated on even further. The discussion of system modeling in chapter III comments on the decision as to appropriate level of detail in a model.

Almost all operational systems consist of groups of subsystems, each of which contains one or more activities. Usually, it is not possible to study all of these activities simultaneously, often not even close in time to one another. This is true particularly in the case of systems that already are functional but are thought not to be as efficient as they might be; that is, not producing the greatest possible effect for the level of resources being consumed. The question is, when it is not possible to undertake all the potential improvements at once, how are priorities set?

The first step leading to setting priorities is, using the graphic model, to see how the system could be divided into discrete subsystems. Figure 2-2 shows a model of a system aimed at reducing the severity of diarrhea by means of increased use of commercial oral rehydration salts (ORS). In this example, the system could be divided for analytic purposes into separate subsystems or modules dealing with selection, training, and supervision of community health workers; CHW-villager interaction for education and motivation; mass media education and motivation; health center-based education; ORS central availability; and ORS distribution and local availability.

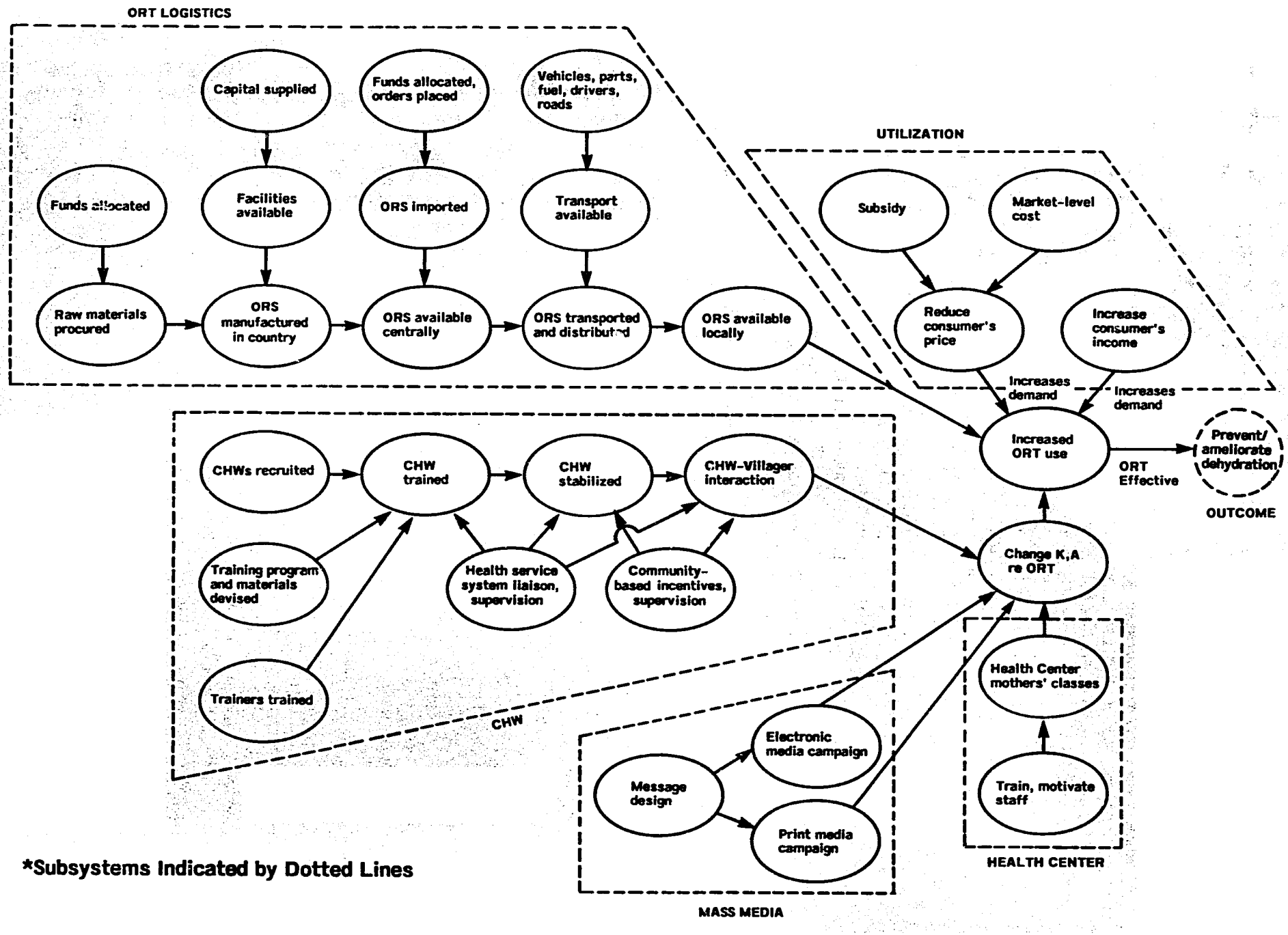
Moreover, subsystems such as those in figure 2-2 usually contain several activities. It may not be feasible to study all of the activities of even one entire subsystem at one time. For example, system managers may or may not be prepared to deal with developing training programs for community health workers, improving CHW recruitment methods, devising CHW retention incentives, and improving or developing supervision schemes all at the same time, even though all these factors affect the outcome of the CHW-villager interaction process. How, then, to determine where to start?

Establishing Research Priorities

In general, the major criterion for setting priorities is to try to obtain maximum possible assurance of achieving the system's objectives. Thus, the researcher looks first at the system as a whole, then as a cluster of major subsystems, and finally at the components and interactions that determine the output of each subsystem. The researcher asks where one should expect modification to produce the greatest positive impact on the system's output. This decision could be based on information already at hand about this particular system or about others similar enough to be expected to behave the same way.

Sometimes, numerical data such as correlations and regressions are available to relate variables to one another. Other times, a certain amount of new data may have to be collected. Sometimes, this important decision is made intuitively. However, several

Figure 2-2.--Model of a System Aimed at Reducing Severity of Diarrhea*



*Subsystems Indicated by Dotted Lines

techniques for bringing group judgment to bear in a systematic way are available. Among them are the use of interaction matrices, Nominal Group Technique, and Delphi. These are discussed in chapter III.

Occasionally, priorities are pre-determined. The analyst may simply be handed a problem in which certain decisions already have been made, possibly as a result of previous analysis or for political or social reasons. For example, a decision may already have been made to attack the problem of ameliorating the effects of diarrhea by means of CHWs because CHWs already are in place and because they have other functions as well. The problem in this case, then, is not to determine whether the CHW approach would be more or less effective than using mass media or mothers' classes by the health center staff to change knowledge, attitudes, and practices (KAP) regarding ORT; the problem is how to overcome the existing operational problems involved in this component of the strategy.

PHASE II: SOLUTION DEVELOPMENT

Having described and analyzed the system, and established priorities within the system, the researcher is ready to proceed to the next phase in the OR process: development and evaluation of potential solutions. The steps in this phase are described below.

Specifying the Solution Objective

The process leading to the development of an acceptable solution to the operational problem begins with specification of the solution objective. The solution objective is a statement of the nature of the desired solution to the operational problem. Solution objectives usually are stated in terms of system efficiency, that is, conservation of input resources and/or maximization of output(s).

Depending upon the situation, the decisionmaker may specify that resources are fixed and ask for maximum output for that level of input, or specify some minimum output to be achieved and ask that this be done with minimum input of resources. For example, the decisionmaker might indicate that a certain cadre of personnel are available and ask how best they might be employed to maximize the number of children immunized. Or, if an expanded program of immunization calls for the immunization of at least a certain percentage of children, then the solution objective would be to accomplish this at the least cost in person-hours.

A third type of solution objective may also be specified. Instead of fixing either inputs or outputs, the decisionmaker may request that the analysis find the most efficient combination of inputs and outputs, that is, the highest ratio of output to input. For example, in an immunization campaign, the solution objective may be to get the most children immunized per unit of input resources (measured in staff-hours, costs, vehicle days, or any other resource, or a combination of resources). Even in these cases, however, it is unlikely that available resources would be unlimited or that some minimum acceptable level of output would not be specified. Surely no solution would be acceptable that ultimately immunized only a small percentage of children even though it did so at minimum cost.

Closely related to the specification of the solution objective is the development of an objective function. The objective function is a statement of the relationship between actions that a decisionmaker may take and the outcome of those actions. The solution objective indicates how the objective function should be solved; this is usually in terms of minimizing or maximizing the output variable.

As an example, it may be known from previous studies that each unit of oral rehydration therapy offers the prospect of saving the lives of **x** number of children under age five and that each unit of immunization can save **y** lives. The number of lives saved (LS) equals the sum of those saved by doing a specific number of ORT and those saved by doing a specific number of immunizations (IMM). In this case, the objective function could be shown as an equation:

$$LS = (x)(ORT) + (y)(IMM)$$

The solution objective would be to maximize the number of lives saved, and the analysis would be aimed at determining how much oral rehydration and how many immunizations should be done to save the most lives.

Researchers and decisionmakers must resist the temptation to simply declare that the purpose of the research is to find the "best" set of actions to resolve the operational problem. "Best" must always be defined in terms of how actions which could be taken will affect the output of interest and what is desired in terms of output. It is true that many problems faced by decisionmakers in the field of primary health care are not as neatly quantifiable as the simple example shown above, but with some thought almost any problem can be set up in terms of a roughly quantifiable objective function and a declaration of how it should be optimized. An example would be research into a means for training mothers to implement oral rehydration therapy with home-prepared salts. If the possibilities for training mothers consist of 1) using community health workers as trainers, 2) using health center staff, and/or 3) using mass media, then the general form of the objective function would be:

Amount of learning = f (training methods, effectiveness of each method)

(The "f" is read as "is a function of".) "Learning" could be quantified as the proportion of mothers who learn satisfactorily. The solution objective would be to maximize the amount of learning.

In an objective function, terms like **x** and **y** (in the ORT-Immunization example) and method effectiveness (in the example above), which define how variables relate to the outcome, are called parameters. As noted, sometimes data are available to tell the researcher what values the parameters should have. Other times, however, such data are not available, and it is necessary to find other means for estimating what these might be. One possibility, of course, is to mount a survey or other study to gather this information. When this is not feasible due to cost, time, or other constraints, another approach frequently used for estimating parameters is that of group consensus, e.g., nominal group and Delphi.

Specifying Decision Variables and Stipulating Constraints on the Solution

Decision variables are those factors that both play a role in determining how a system functions and also are within the control of the system managers. Although this broad definition could include many factors in the system, the decision variables of concern to the analyst are the relative handful that are involved in the part of the system being studied. In the objective function, the decision variables represent those factors which will be acted upon by the decisionmaker in order to meet the solution objective. Thus, in the examples given above, the decision variables are the amount of ORT and the number of immunizations to be provided in the first example, and training methods in the second.

If the solution to the problem could be developed merely by inserting values for the variables and parameters in the objective function, the analytic process might be quite trivial. In the ORT-Immunization example above, one would simply need to know which of these actions resulted in more lives saved per unit and then do all of that one and none of the other. However, very often, factors exist that limit the practical range of one or more decision variables. These limiting factors are called constraints. Constraints are factors that are beyond the control of the system managers. They can be thought of as providing the boundaries of feasible solutions.

One very common constraint on inputs is cost, perhaps the cost of additional resources or the cost of a new organizational approach to service delivery. For example, there may be some specified maximum funding that central government decisionmakers are prepared to make available for training CHWs or for immunization programs.

Other types of constraints are infrastructural, such as the reliability (reliable/unreliable/seasonal) and nature of transportation (private auto, bus, bicycle) and communications (telephone, mail). Other constraints are socioeconomic and societal, such as population density and the laws, ethnicity, customary roles of men, women, the elderly and the young, and educational levels and occupations of potential participants in the system. Still other constraints are natural, such as weather and terrain.

Where minimum levels of system performance are required--a very common situation--outputs also may be viewed as being constrained. For example, policymakers may require that a certain minimum percentage of children be immunized or that a certain number of CHWs be trained. Thus, any solution which did not promise to meet these constraints could not be considered acceptable. In such cases, the solution objective is usually to minimize the resources required to meet the specified output.

Constraints are not necessarily permanent. Although the analyst initially takes them as given, he may be able to show that a particular constraint is having an exceptionally deleterious effect on the feasibility of an otherwise excellent solution to the operational problem. In that case, consideration should be given to relaxing the constraint, if this is at all feasible. For example, on the one hand, it is unlikely that managers of a primary health care delivery system can do much about educational levels or the lack of spare parts for private or public transportation. But on the other hand, policymakers may be influenced to change the laws governing health services delivery or to make more money available for training programs.

It should be noted that not all uncontrollable factors are constraints. Sometimes certain factors exist which in fact facilitate obtaining the solution desired. For example, in some cultures payment for a good or service enhances its value in the eyes of the recipient. This may make it easier to institute a small charge for a particular service that people really want and use that money to finance another service that they see as less desirable.

Selecting a Model for Solution Development

The selection or development of an analytic model as a tool in the development of a solution to the operational problem is integral to operations research. One well-known text, in fact, states categorically that "modelbuilding is the essence of the operations research approach."(1)

A model is a simplified representation of the real world. Since its whole purpose is to simplify reality enough to make systematic analysis possible, the model should be only complex enough to account for the most essential features of the real world situation it is

intended to portray. For example, a model intended to assist in the development of a scheme for community financing of primary health care certainly would incorporate variables accounting for the community's ability to raise funds. However, it generally would not consider the variability of world commodity markets, even though in the long run these would play a role in determining the community's income.

Models may be very realistic and explicit, or quite abstract. Most explicit is a category of models called iconic; these are virtual images of real objects. Dolls, toy automobiles, and photographs are iconic models. Such models play valuable roles in industry and the physical sciences (e.g., wind tunnel tests on a new airplane design). Their role in operations research on health services is not as significant, although they can be useful teaching and demonstration devices in specific primary health care components, such as family planning.

A more abstract class of models are those called analogs. An analog model is one in which the properties of the object being modeled are exchanged for visual attributes in the model. A map is an analog model of a city or a country, with lines representing the location and length of roads and political boundaries, dots or other symbols representing the location and perhaps size of cities, and other symbols representing other physical features, such as lakes and mountains. A flowchart is an analog model depicting the movement of goods, the sequencing of activities, or the flow of information. A graph is an analog model in which the location of points or the height of bars relative to some scale depicts the magnitude of a variable. A system model is an analog of a real situation, which shows what the elements of a system are and how they interact with one another.

The most abstract class of models are mathematical models, in which symbols are used to represent essential features and their behavior in the real situation. The equation that relates the hypotenuse of a right triangle to its other two sides ($c^2=a^2+b^2$) and the general regression equation which describes how two variables relate to one another ($y=mx+b$), are examples of mathematical models. We have already used an equation to show ORT and immunization could be related to lives saved. Traditionally, operations research has relied heavily on mathematical models as analytic tools.

Certain kinds of health service operational problems can be fitted into operations research models that have been developed to solve whole classes of problems, especially those originally formulated for industrial applications. Typically, these mathematical models are accompanied by a set of step-by-step directions, called an algorithm, for applying the model and solving it; there may also be a computer program available to solve the equations of the model. Examples of these problem classes and their health services applications are:

Queuing: x providers serve y recipients who arrive for service at a fixed or variable, known or assumed, rate. A typical application would be to determine how appointments should be scheduled in an ambulatory clinic so as to obtain simultaneously the shortest possible waiting time for the patients and the least possible unproductive time for the staff.

Resource Allocation: A specific set of goods or services is to be obtained with a minimum input of resources (e.g., staff, money, vehicles), or conversely, a fixed amount of resources is to be used to produce the maximum amount of goods or services. A typical application would be in determining the most cost-effective mix of physician-hours, nurse-hours, and auxiliary-hours to meet the service needs of a population with known morbidity characteristics. Techniques of mathematical programming are applied to solve allocation problems. Linear programming is used

when the problem may be formulated as a single objective to be optimized in the face of a set of constraints. Goal programming is used when multiple objectives must be considered simultaneously and a solution derived that satisfies the most important objectives while nearly satisfying the less important ones.

Inventory: A constant supply of goods is to be maintained, given such constraints as expected utilization rates, storage and transportation costs and limitations, and required ordering leadtimes. The obvious example is maintenance of supplies of drugs, vaccines, nutrition supplements, and so on, at point of service.

Networks: Goods or service providers must reach several places, and the order of movement can be varied so as to meet specified constraints and some definition of "most efficient"; for example, least time or least cost. An example would be the scheduling of a vaccination team to cover a particular region in which multiple vaccination points will be established sequentially. An important variant of network analysis is the scheduling of a sequence of tasks required to complete a project or program in the minimum possible time. The technique employed is called the Critical Path Method.

Cost Analysis: There are two categories of cost analyses, cost-benefit and cost-effectiveness. In cost-benefit analysis (CBA), a ratio is produced in which both numerator and denominator are expressed in the same units, most often money. CBA is most often used to compare the relative value of programs that have different objectives or even different goals; for example, the relative worth to a country of a malaria prevention campaign versus a tuberculosis immunization campaign, or even malaria prevention versus a national television network. In CBA, program costs are not too difficult to capture, but conversion of benefits to purely financial terms often presents extreme conceptual problems (e.g., how to value feelings of malaise, fever, and nausea when productivity is not affected?).

In cost-effectiveness analysis (CEA), the numerator again is cost, but the denominator may be expressed as any definition of "effective"; for example, community health workers trained, persons vaccinated, infant deaths averted, or couple-months of contraceptive protection. CEA is most often used to compare different approaches to achieving the same objective; for example, intensified use of oral rehydration therapy by means of improved CHW training, a mass media education campaign, subsidization of oral rehydration salts in the marketplace, or some combination of these. In each case, the analytic outcome is expressed as cost per unit increase in use of oral rehydration therapy. It is also possible to analyze outcome in terms of effectiveness per unit cost (i.e., fixed cost).

Simulation: In this model, key variables in the system are related to one another so that change in the value of one variable is reflected in changed values for the other variables that it affects. The model begins with particular values stipulated for each of the variables. The researcher can then change one or more values to see what effect these changes would have on other variables in the system, particularly those that represent the output of the system, as for example, the number of children with diarrhea who are treated with oral rehydration therapy.

Complex simulation models require computer-assisted calculation. (In fact, whole computer languages are devoted to facilitating simulation modeling and analysis.) There are very few "standard category" simulation models; each is tailored to the system at hand.

A typical use of simulation in health services research is in forecasting demand for services, in which the factors that affect demand (e.g., epidemiologic factors,

population attitude toward the service system, distance, cash cost, opportunity cost) are linked in a model and then varied to estimate change in demand. A special version of simulation, particularly useful in training as well as planning, is operational gaming. This is a role-playing simulation in which a handful of people simulate an entire system and make a series of operational decisions based on the kind of information (or partial information or misinformation) they might have in the real-life situation they are simulating, including reaction to decisions made by others earlier in the system. Decisions and specified conditions must be recorded so that the consequences of each "move" can be discussed at the end of the game.

Game Theory Application: This system of decisionmaking modeling is applied to situations in which alternative strategies for achieving a particular outcome are available, but in which the ultimate value of each strategy is dependent upon an uncontrollable environment in which the system operates and each strategy has some social cost attached to it. Policy decisions required to move into a major vaccination campaign in the face of a potential outbreak of a particular disease fit this model. Questions of who, how, where, and how fast, each have some social cost and tradeoffs (assuming resources are not unlimited), and the value of whatever kind of campaign is finally mounted is greatly dependent on uncontrollable factors.

For example, if a government prepares, on the basis of evidence in other countries, to face a major cholera epidemic that ultimately stops short of its own borders, then the opportunity cost may have proven too high. This is especially true if it turns out that the same resources could have been used to thwart a measles or a polio epidemic that does occur. This "decisionmaking under risk," though fairly straightforward computationally, does depend heavily on group values. And the "right" answer for one group, who may be risk-averting by inclination, may not be right for another group, who might opt for the possibility of a higher payoff even in the face of somewhat greater risk.

If one of the mathematical model classes just described does not reasonably fit the situation, then the analyst must turn for his solution-developing model to a more heuristic approach. Heuristic techniques, in contrast to the mathematical models described above, tend to incorporate variables that are nominal or ordinal rather than regularly intervalized or continuous.

For example, in response to the question "Who shall provide direct supervision to the CHW?", the "values" assumed by the variable "who" may be 1) the village health committee, 2) the local health center nurse, or 3) the public health nurse from the district hospital. Another example might be "What primary health care services does the target population perceive as most desirable?" The "values" might be 1) therapeutic services for children, 2) immunization, 3) growth monitoring, 4) health education, 5) assistance with potable water, 6) assistance with sanitation, 7) assistance with local food production, or others.

Heuristic models are not necessarily expected to produce the optimum solution. They are practical attempts to generate good, satisfactory solutions, based on what is known about the economics, politics, and sociology of the situation, to problems that contain some nonquantifiable elements.

Those working in the area of primary health care have found that many more operational problems are amenable to a reasonable solution by these heuristic approaches than an optimum solution by mathematical models such as linear programming. This is not to say, however, that the latter do not have valuable applications (see the Appendix).

They do, and they should be used when the research problem is amenable to solution by such analysis. The researcher whose own expertise is more in service delivery than in quantitative analysis may need the assistance of an OR specialist to help determine when and which of these techniques is applicable.

Determination of Data Needs and Data Collection

It is likely, particularly when one of the mathematically grounded OR models is employed, that even after acquiring the data necessary to construct the system model, additional data will be needed to perform the analysis, using the analytical model. For example, if the operational problem is maximization of the effectiveness of CHW training at or less than some ceiling cost, a cost-effectiveness model will be employed, and the cost data for different training strategies will not necessarily have been developed earlier.

In another example, suppose the objective is to maintain a supply of specified medications at a group of health posts. The analytic approach could be to use a forecasting model to determine what the supply should be and an inventory model to determine how much and how often specific items should be ordered. Data that would not have been necessary to construct the system model, but that would be required for the analytic models, would include such variables as demand at point of distribution, storage life and capacity, transportation subsystem capacity and speed, and period between ordering and arrival of materials at the health post. Requisite data may be obtainable from existing records (e.g., health statistics, health system service records, census records, or previous studies) or may have to be generated (e.g., by survey, case study development, or prospective recording of health service statistics).

Solution Development

When the analytical model has been designed and all the requisite data obtained, potential solutions can be developed. It is important to observe the constraints stipulated earlier so that those solutions that are not feasible, that is, that require constrained variables to assume values that are "out of bounds," are discarded.

In the case of the mathematical OR models, inserting numerical data values into the equations and performing the computations will yield a "best" solution; that is, the one in which the values for all of the decision variables come closest to satisfying the objectives. For example, in the medication supply example just cited, the output of the model will be a frequency of ordering indicator that meets a stipulated minimum probability of having the medication on hand each time it is needed. Another example might be the development of a training program for community health workers in which the objective is stipulated in terms of cost-effectiveness. The output of the analytic model is a training strategy in which the selected values for the decision variables (e.g., location of training, type of trainer, and means for presenting the information) yield the best ratio of cost per trained CHW.

Heuristic models may not produce such precise answers, but may yield several courses of action that look both feasible and roughly equally effective. In the example dealing with who should supervise the community health worker, it may turn out that the analysis eliminates the district public health nurse from consideration but cannot produce a clear decision between the village health committee and the local health center nurse. It then may be necessary to set up a field test consisting of a comparative evaluation of both courses of action.

In contrast, questions that can be resolved in the form of a single solution, as is the case generally for those problems amenable to mathematical analysis, require a different

type--usually simpler and less costly--of field test. This difference, and its implications, are discussed in Phase III: Solution Validation, below.

Sensitivity Analysis

A sensitivity analysis is conducted in order to determine how much the outcome of the analysis might change if some of the constraints applied were changed or if different values were selected for decision variables. Relationships between input variables (i.e., those that are entered into the analysis either as constraints or as decision variables) and the output variables (i.e., those that are the objectives of the analysis) are not necessarily linear. That is to say, a change of one unit in one of the input variables does not necessarily imply a change of a constant multiple of output units.

The economic concept of price-demand elasticity is a good example of a nonlinear relationship: doubling the price of a good or service does not necessarily translate into a halving of the demand for it. Even if in some cases it did, the reverse is not predictable: halving the original price will not necessarily double the demand.

In the medication order and supply problem, changing the constraint on the variable "probability that the drug will be in stock when prescribed" from, for example, 80 percent to 90 percent may have a drastic effect on the decision variables "frequency of ordering" and "size of order placed." Moreover, changing drug availability from a 90 percent to a 95 percent probability may have an even greater effect on the decision variables than going from 80 percent to 90 percent.

Sensitivity analysis serves two purposes. First, it allows the analyst to determine which of the factors in the analytic model have the strongest effect on the outcome of the analysis; in other words, to which variables is the analysis most sensitive. It is these variables that require the greatest accuracy in their estimation.

When data for estimating the value of a particular variable are derived from sampling, accuracy can be increased in either of two ways: one, increasing sample size, and two, improving the accuracy of each measurement. Each approach has implications for the cost of obtaining the necessary data. When data concerning especially sensitive variables are obtained through judgmental techniques (e.g., nominal group, multiple-criteria utility assessment), the analyst must be aware that if a different group had been asked to make the judgment and had given a slightly different response, the outcome of the analysis could have been quite different.

The second purpose of a sensitivity analysis is to give policymakers and decisionmakers choices that enable them to consider tradeoffs on a rational basis; that is, what the outcome of a change in policy might be in terms of some social value. For example, suppose that the sensitivity analysis shows that changing an originally posed requirement for a 95 percent probability of availability of drug x to a 90 percent requirement could free a large amount of resources (e.g., storage, transportation, money) for another use in the system. A value judgment would have to be made. Note that the decisionmaker might decide on the spot, or might call for an analysis of what the change from 95 percent to 90 percent might mean to those affected. Either way, the OR analysis now has given the decisionmaker information on a range of possibilities.

PHASE III: SOLUTION VALIDATION

Up to this point, except perhaps for some field activity to acquire data for the system model or the analytic model, the analysis has not involved any actual intervention in the target system. In some cases, decisionmakers who participated in the operations

research may decide that they are confident enough of the result to move directly into full-scale implementation. Where the decisionmakers did not participate directly, a full briefing on the research and its outcome may be enough to allow them to move directly to implementation.

Often, a certain amount of "reality-testing" and/or resolution of still open questions may be in order. One possibility for doing this would be to use role-playing to simulate the system with the new solution in place. The players could include the decisionmakers and others not normally involved in that part of the system, or the actual staff who would carry out the regular implementation could be employed to "play" themselves. For example, where the operational problem had concerned the development of teaching materials for training community health workers, the trainers might "present" the material to an audience of decisionmakers and others.

Where briefings or simulations either are not sufficiently convincing or cannot be expected to resolve some issues--for example, how well real CHWs might absorb material--a more realistic test may be necessary. This usually is done by means of a small-scale field test.

The goal of a field test should be to validate the solution formulated in the solution development phase. When the solution development phase has produced two or more comparably effective solutions to the operational problem, the field test would be designed to help choose between them. A field test is the "acid test" of the soundness of the system model, the analytic model, and of the assumptions made about how the people involved in the system (e.g., providers, recipients, managers, policymakers, community members) do or will behave under the circumstances specified.

Indicators are variables which measure change in the factors of interest in the field test. Indicators may be very direct measures of these factors or they may of necessity be indirect. If, for example, the field test is aimed at determining which of two different strategies is more effective in getting mothers to cooperate in an immunization program, then the indicator is simply a count of the number of children who are brought for immunization. If, on the other hand, the question is which of two training strategies for community health workers will lead to better performance on the job, then the indicators are some indirect measures that are expected to correlate with future performance; examples might be knowledge of the material presented, skills acquired, and attitude toward the work.

The field test should be designed to accomplish its purpose as quickly and inexpensively as is consistent with reasonable certainty of its own validity. It should not be allowed to become such a lengthy and elaborate process that the value of the entire operations research task is seriously undercut in the view of the decisionmaker who must implement its results. Important components of strategies to enhance the results of field testing include selecting an appropriate study design and minimizing factors that undermine validity.

Field Test Study Design

Study designs may be categorized as experimental, nonexperimental, or quasi-experimental. Each design carries an implication for certainty of causal attribution; that is to say, the degree of certainty that the changes observed in the variables of the objective function (i.e., observed outcomes) actually have been caused fully and exclusively by the designed intervention. Each of these designs is discussed briefly, but it is outside the scope of this paper to provide detailed instruction in design methodology.(2)

True Experimental Designs:

The most powerful design in terms of causal attribution is the true experiment, in which the units of observation (people, villages, districts, etc.) are assigned randomly either to a treatment group or to a control group. The treatment in this case is whatever interventions are made in the primary health care system, for example, modification of the training program for CHWs. The inherent assumption is that these changes are the only significant differences between the two groups with respect to factors that might influence observed differences in the variables that measure outcome. The observed differences then are tested statistically to see if they are greater than those that would be expected from predictable random variation.

True experimental designs often are difficult to apply in social settings. Sometimes there may be ethical problems, such as withholding from those in the control group an intervention that has a high expectation of success. But often, given the reality of scarce resources, a new service or mode of operation cannot be extended simultaneously to all potential beneficiaries.

The more frequent confounder of the true experimental approach, however, is the required assumption that, except for the treatment variables, everything else about the two groups remains equivalent over time. One way to cope with this problem is to employ a more complicated, multivariate analysis, in which, in addition to outcome variables, one also obtains measurements for a number of other factors that influence outcome. The analysis then is aimed at factoring out those effects and leaving only the effect due to the change in the decision variables from preintervention to postintervention. This type of analysis also provides an opportunity to test more than one value level for each decision variable if this seems useful.

Another problem with a true experimental design for a field test is that the statistical analysis requires sample sizes that may be impractical in many situations. For many operational problems, the unit of observation may not be individuals, but entire communities; for example, when one is dealing with community financing of primary health care or community participation in primary health care, or perhaps entire commodity distribution networks. The numbers available for validation of an operational solution may not be large enough to meet the distributional assumptions underlying the statistical techniques available.

Nonexperimental Designs:

At the other end of the spectrum, the weakest designs in terms of causal attribution are those that are nonexperimental. Weakest of all is a design in which a locale is selected, the intervention implemented, and outcome measurements taken. Note that although this would be a poor approach to validating a modification to an existing system, it is, in fact, quite reasonable in a case where the intervention is unique and the question simply is, will it work? An example might be a pilot test, for the first time in a country, of community financing of primary health care. The operations analysis should have provided the best answers to the questions of what services should require a fee, what the fees ought to be, how the money should be collected, and how the financing scheme should be managed. The test then is, can it be sustained, and will it deliver the service expected? The pilot test implements the program in the place selected and continues the observation for a convincing length of time. There is nothing to which to compare it.

A better--still nonexperimental--design when an existing system is to be modified is the pretest-posttest design. Here, measurements are made of the values of the objective function variables, the interventions implemented, and new observations taken. The "pre"

and "post" measurements are then compared statistically to see if the differences are greater than those expected on a random variation basis. A major problem with this type of design is that it cannot account for changes in the outcome variables that might have occurred even without the deliberate intervention, but as a result of changes in other factors. Once again, to protect against this eventuality, or at least to help estimate its impact, data on other factors are gathered and examined for relationship to the observed change in the outcome variables.

Another nonexperimental design that may be useful when preintervention observations are not available or are not feasible is what has been called static-group comparison, in which a treatment group is observed posttreatment and an untreated comparison group is studied at the same time. Obviously, the designers should ensure that the two groups are as similar as they possibly can be with respect to factors that are thought to influence the objective function variables so that the assumption of equivalence beyond the intervention will be as valid as possible.

Quasi-experimental Designs:

Finally, there does exist a middle ground between true experiments and complete nonexperiments. The designs in this category have been dubbed quasi-experimental and, expectedly, are compromises with a true experimental design. The most important compromise is elimination of the randomness requirement. However, one must then accept the somewhat reduced security with which conclusions can be drawn about the results of the field-validation test.

One of the most useful of these designs, applicable when the number of units of observation (i.e., the sample size) is sufficient to permit a valid statistical analysis, is a parallel of the powerful experimental design using treatment and control groups with pretreatment and posttreatment observations. In the quasi-experimental design, the assignment of observation units (i.e., cases or subjects if they are people) to one group or the other is not a random process from a single population of eligible units. Instead--and usually for some very practical reason related to what can and cannot be done to people in a real-life setting--there is some reason that one group receives the "treatment", (i.e., the intervention) and the other does not.

To take a simplified example, suppose that the field test is aimed at validating the effectiveness of a newly proposed training scheme for community health workers that, it is expected, will increase the use of oral rehydration therapy when compared to an existing training scheme. Since the community health worker is linked to a village, there is no opportunity to assign new-scheme and old-scheme health workers randomly to villages. Instead, a group of community health workers would be selected for training with the new method according to whatever criteria have been agreed to by the system managers (including, of course, a strong element of volunteerism), and a group of non-participating community health worker-village units would be selected as a comparison group. Measurements would be made in both sets of villages before the community health workers are trained and then again in both sets of villages after the newly trained community health workers are at work.

Naturally, the treatment group and the comparison group would be matched as best they could in terms of the social, demographic, and economic factors that are expected to influence the outcome of the intervention. Nevertheless, this in no way is equivalent to the random selection criterion that underlies a true experimental design.

Another quasi-experimental design common to social science settings is a time series analysis, an extension of the nonexperimental pretest-posttest designs. In a time-series

analysis, a single group is used, but several measurements of the outcome variables of interest are made afterward over the course of time. The value of this design is that the analyst can plot trends in the value of the factors of interest before and after implementation and can detect changes that were taking place even before the intervention and thus are attributable to some cause other than the deliberate intervention.

An example of this might be a new program aimed at achieving higher levels of child immunization by means of enhanced community participation. Measurements are taken 6 months, 3 months, and immediately before the new program is instituted, and then at 3 months and 6 months after the program begins. Figure 2-3 illustrates two hypothetical results.

It may be seen that, in result A, if one were to compare the proportion of the target population being immunized immediately before the institution of the new program and the proportion either 3 or 6 months later, one could easily conclude that the program is effective. But seeing the trend for some time before the new program began would force one to conclude that other factors are at work and that, in fact, the new program may have contributed little. In result B, one would again conclude that change already is occurring, but that the new program has accelerated the trend.

One can conceive of many other variations in the plot of outcome measurement in a time-series analysis, including an important one in which the plot is "sawtooth" in character. As is shown in figure 2-4, single pretest and posttest measurements could make a true upward trend look as if the program had actually resulted in (or failed to prevent) a decline in immunization.

Figure 2-3.--Time-Series Analysis of a Child Immunization Program

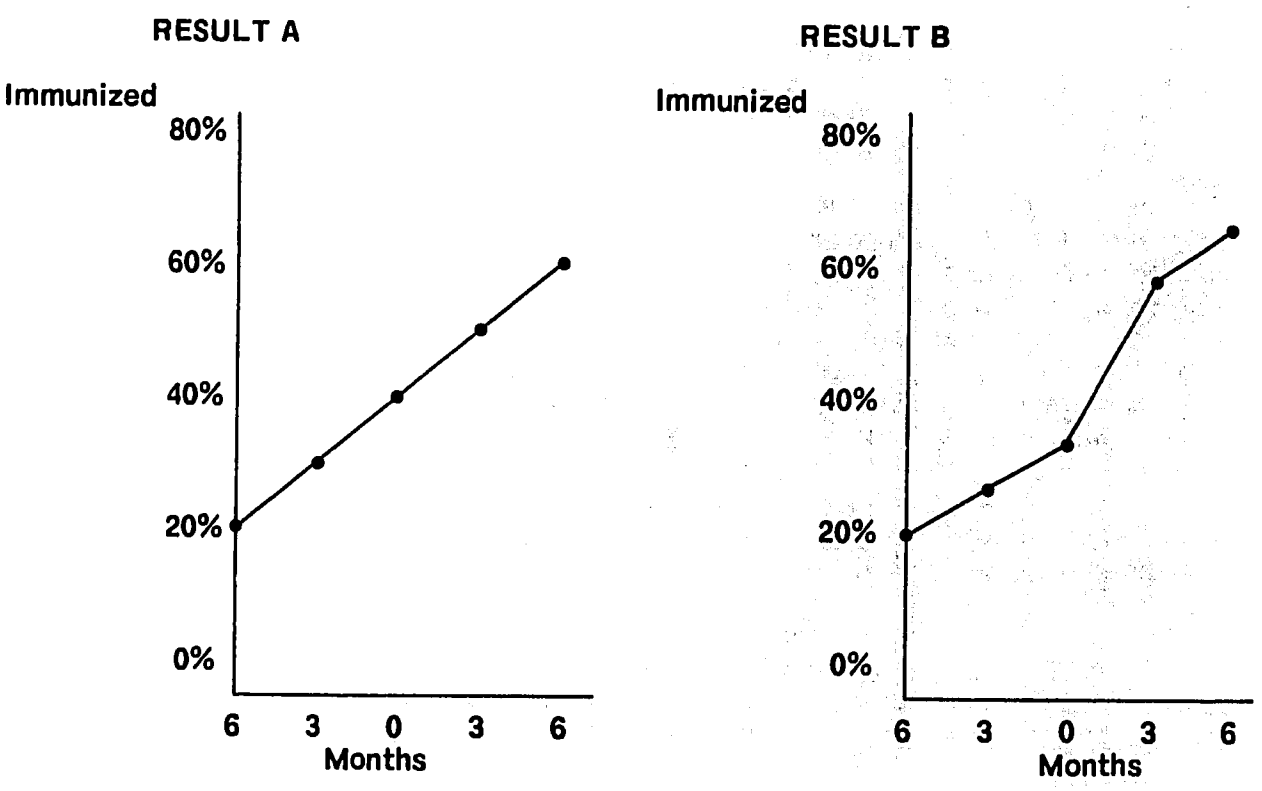


Figure 2-4.--Time-Series Analysis Showing "Sawtooth" Result

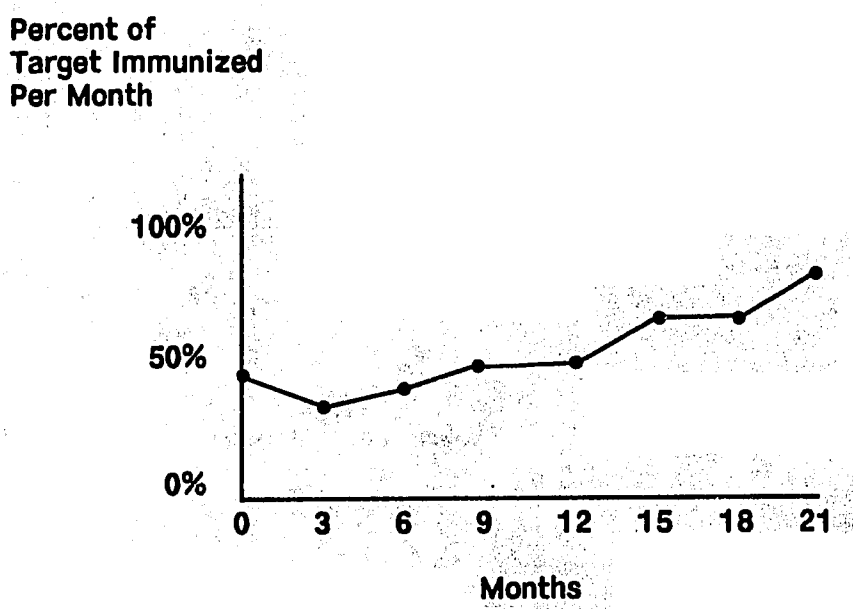


Figure 2-5 summarizes salient characteristics of the three design categories and illustrates commonly used designs in each of them.

Field Test Validity

Before leaving the subject of field test design, a few words are in order concerning the important concept of experimental validity. Validity might also be called credibility; that is, how believable is the outcome of the field test. Campbell and Stanley divide validity into two categories, internal and external. Internal validity concerns the credibility of a particular experiment; external validity concerns the credibility of generalizations drawn from a particular experiment with respect to other populations and other circumstances.(3)

Obviously, validity and those factors that reduce it have to be of great concern in the design of tests aimed at validating solutions. Following is a very brief discussion of several of these factors. A fuller discussion may be found in Campbell and Stanley and a very thorough discussion in Cook and Campbell.(4)

Extraneous events (called history by Campbell and Stanley): events that occur between preintervention and postintervention measurements in addition to the planned intervention and that also affect the observed outcome of the experiment. An example might be, in the case of a program aimed at increasing the use of commercially purchasable oral rehydration salts, changes in levels of disposable income due to a particularly good harvest or employment opportunity.

Maturation: changes in characteristics of some system components that are linked to the passage of time rather than to a programmed intervention; for example, increasing receptivity to innovation as a result of continued exposure to electronic media.

Testing: changes in responses to testing that derive from increased familiarity with the testing materials and procedures.

Figure 2-5.--Field Test Designs

EXPERIMENTAL

Most powerful in terms of causal attribution; requires random assignment experimental units (cases)

Typical models:

Pretest-posttest	Control Group	O		O
	Experimental Group	O	X	O
Posttest only	Control Group			O
	Experimental Group	O	X	O

NONEXPERIMENTAL

Weakest in terms of causal attribution; no "control" group

Typical models:

Pretest-posttest	Experimental Group	O	X	O
Posttest only	Experimental Group		X	O

QUASI-EXPERIMENTAL

Mimics true experiment; but not random assignment of cases

Typical models:

Pretest-posttest	Comparison Group	O		O
	Experimental Group	O	X	O
Posttest only	Comparison Group			O
	Experimental Group		X	O
Time series	Experimental Group	O O	X	O O

Note: O = Observation; X = Intervention

Instrumentation: noncomparability of responses that arise because instruments are changed from one measurement to the next. This is a particular problem in serial questionnaire surveying and also with physical instruments such as weighing scales for growth monitoring.

Statistical regression: A statistical artifact may occur when groups are deliberately formed from individual units that have relatively extreme values on the variable of interest. An example would be a group of children selected for treatment of malnutrition on the basis of low weight-for-age. Even without any intervention, a subsequent measurement taken on this group can be expected to show values nearer to the mean of the original group, a change that might be interpreted as improved nutritional status. In fact, such a change is entirely predictable. It is called regression to the mean and simply represents a decrease in random error of individual measurements.

Selection bias: This is a systematic difference between formed groups. It may be a problem when people volunteer to receive a particular treatment and then are compared as a group to an untreated, nonvolunteer group.

Differential attrition: conceptually related to selection bias; systematic dropout from test or control or comparison groups due to factors that play a role in determining the outcome of the test. An example might be loss of an exceptional proportion of better educated community health worker trainees due to urban migration.

Note that true experimental designs, with their random assignment of cases to treatment and control groups, provide the means either for obviating these threats to validity or for accounting for their effects. Quasi-experimental designs generally are somewhat less effective in dealing with threats to validity, and nonexperimental designs are the most likely to run into validity problems.

The threat to the external validity of a field test derives from the complexity of social systems and the virtual uniqueness of any selected group. An enormous number of factors interact with one another in determining individual and group response to any set of stimuli--in this case, not only the planned intervention but also the many other factors that act to direct behavior. Thus, it is not easy to be certain that the outcome seen in one or a few groups under the circumstances that prevail is predictive of the behavior of other groups under other circumstances.

The decisionmaker does not demand absolute certainty as a prerequisite to taking action; instead, the decisionmaker and the analyst deal in "probability." If there is a high probability that most of the important characteristics of the test and control or comparison groups and the situational factors are sufficiently similar to those of the entire target population, then it is reasonable to assume that the field test is sufficiently predictive of what would happen if the intervention were applied to the entire population. This same principle is applied in any statistical analysis.

Implementing the Field Test

Planning for implementation of the field test requires a determination of requisite resources, development of a management scheme, development of training materials and a training program, arrangements for obtaining human and other resources needed, and design of an information system to gather the data required to evaluate progress as the test proceeds and to evaluate the outcome at its conclusion. Some preparation of the target population may also be necessary.

Evaluating and Modifying the Solution

It is important to conduct a more or less continuous assessment while the test is in progress so that any refinements of inputs can be made while there is still time to see what the effect of these adjustments will be.(5)

For example, in a field test of a community financing scheme, it may be found early in the test that the price of a particular service or good has been set a little too high to enable it to reach its expected use-rate in a particular segment of the population. The analysts and decisionmakers may then need to look again at the sensitivity analysis (or do another) on prices to see how a reduced price would likely affect use-rates. They would then institute a new pricing structure and continue to study its impact.

In the same example, analysts may discover other, nonquantitative factors that require some adjustment; for example, the specification of educational or other requirements for the individuals who will maintain financial records for the community.

Integrating the Solution Within the System

Recall that one of the first tasks in using the operations research approach was to divide the larger system into subsystems. In this way, a complex operational problem could be divided into a number of less complex, more easily studied problems. It is important, however, for the researcher to recognize that changes made in one part of the system might have other effects elsewhere in the system. Therefore, as a last step in the OR process the researcher examines the proposed solution in the context of the overall system.

In the example of community financing of health services, for instance, it may be found that any fee, even while helping to support more effective health care for some problems, might also have the unexpected effect of inducing more self-treatment for others. The decisionmakers would therefore have to weigh the net effect of these two outcomes before deciding to institute the proposed financing scheme.

FINAL NOTE ON APPLYING THE METHODOLOGY

The series of steps shown in this chapter should not be viewed as a rigid progression on the way to a solution, each to be completed before the next is begun. For some problems, it may be logical to reverse the order of some steps, to repeat some, or to do more than one simultaneously. The ORT-Immunization problem described in the section on solution objectives is a good example. It is unlikely that the researcher could produce the objective function shown without prior knowledge of what the decision variables would be. Another place where movement backward in the progression is common is at the stage of determining what data are needed for the solution-generating model. If a model has been selected and it turns out that the data needs of that model can not be met, then it is necessary to reconsider the model. Obviously, some models are discarded even before they are seriously considered because it is immediately obvious that the requisite data could not be obtained or else could only be obtained at some cost that made a second-choice model a better buy.

In sum, the methodology shown should be taken as a guide only. In any operations research undertaking, judgment and a flexible approach should prevail. The goal of the researcher should be to get the job done in a reasonable period of time and with an input of resources in proportion to the significance of the research problem.

NOTES

1. Harvey M. Wagner, Principles of Operations Research--With Application to Managerial Decisions (Englewood-Cliffs, NJ: Prentice-Hall, 1969).

2. For a concise presentation of principles of design and analysis in social science settings, see Andrew Fisher, John Laing, and John Stoeckel, Handbook for Family Planning Operations Research Design (New York: The Population Council, 1983). A much fuller discussion of quasi-experimental design and analysis may be found in Thomas Cook, and Donald Campbell, Quasi-Experimentation--Design and Analysis Issues for Field Settings (Boston: Houghton-Mifflin, 1979).

3. Donald Campbell and Julian C. Stanley, Experimental and Quasi-Experimental Designs for Research (Chicago: Rand-McNally, 1963).

4. T. Cook and D. Campbell, op. cit.

5. A concise summary of important aspects of evaluation may be found in the chapter by K. Hennigan, B. Flay, and R. Hoag, "Clarification of Concepts and Terms Commonly Used In Evaluation Research", in R. Klein, et al., eds., Evaluating the Impact of Nutrition and Health Programs (New York: Plenum Press, 1979). The previously cited Handbook for Family Planning Operations Research Design by Fisher, et al. is also useful.

CHAPTER III

SUMMARY OF SOME USEFUL TOOLS FOR PLANNING AND ANALYSIS IN OPERATIONS RESEARCH

CHAPTER III. SUMMARY OF SOME USEFUL TOOLS FOR PLANNING AND ANALYSIS IN OPERATIONS RESEARCH

The purpose of this section is to provide an overview of some of the tools that have wide application in the problem analysis and solution development phases of operations research in primary health care. No attempt is made to present textbook-level detail sufficient to instruct in their use, although some of the most useful are straightforward enough to require little additional material.

The mathematical models that have already been summarized in the section in chapter II on Model Identification and Development (queuing, resource allocation, inventory, networks, simulation, and game theory) are not discussed here because their application generally requires more mathematical skills than many health care system managers are likely to possess. For those who wish to develop facility in the application of these techniques, many operations research textbooks are available; others may wish to leave these techniques to the operations research specialist. Cost-effectiveness analysis, which was discussed briefly in the same section, is discussed more fully in this section because of its wide applicability and frequent employment in conjunction with other analytic models in the development of solutions.

The techniques that are presented in this section do not require advanced skills in mathematics and are not particularly difficult to learn. The reader is encouraged to practice applying these methods as the need arises. Most of them can be found in detail in an excellent publication aimed specifically at the nonspecialist manager-analyst entitled Systems Tools for Project Planning, by Peter Delp, et al.(1)

The techniques are organized into two groups: those that are most useful in the problem analysis phase of operations research and those whose main application is in the solution development phase. It should be noted, however, that few of these techniques are restricted to only one phase or the other. Under certain circumstances, it might entirely appropriate to use a particular technique in a different phase than is shown here. In some cases, the same group decision technique, such as nominal group, might even be used in both problem analysis and solution development.

TECHNIQUES WITH APPLICATION TO PROBLEM ANALYSIS

System Modeling

["Nothing ever exists entirely alone; everything is in relation to everything else."--Gautama Buddha]

The use of a graphic system model was described in some detail in the section on graphic modeling in chapter II. Probably no other technique assists the manager or analyst so much in clarifying a problem, demanding as it does, thought in depth about what the elements are that constitute the system, how they interact with one another and with the many other factors that affect the system but are beyond the control of its managers (constraints), how the system might be manipulated (decision variables), and exactly what output is likely. It should be considered exceptional not to construct a system model when doing operations research, and it should be the result of a conscious decision not to do so, rather than an oversight. As a rule, it is the detail with which the model is specified that is discretionary, not whether to prepare one at all.

There are two basic types of graphic system models: (a) organizational and (b) means-outcome. Organizational models show relationships between the elements of a single subsystem and between subsystems within a larger system. Means-outcome models

show a sequence of activities and their direct outcomes, in essence a chain of cause-effect links. Not infrequently, the analyst finds it useful to combine both types of models. Graphic system models are sometimes called oval diagrams because it has become customary to show components within linked ovals.

To assist the reader who is not familiar with the general procedure for developing a system model, the method is described below, step by step, along with a simplified example in which one of the objectives is to ameliorate the effects of diarrhea in a village by increasing the use of oral rehydration therapy. The steps in the modeling procedure work "backward" from a statement of the final condition that is the desired effect of the system. These steps include:

1. Specify goals and objectives of the system. (Goal: reduce child mortality due to infectious diseases. Objective: reduce severity and sequelae of diarrhea.)

2. State the condition(s) that will be obtained when the objective is attained. (Villagers will adopt use of oral rehydration therapy as standard home treatment for diarrhea.)

3. Ascertain what event (possibly more than one) must occur immediately prior to attainment of this condition. (The community must have greater knowledge of oral rehydration therapy and must believe in its efficacy.)

4. What must precede this condition? (A community health worker must be active in the village and involved in educating the villagers and, moreover, must either have the oral rehydration salts available or know how to instruct the villagers in home preparation of them.)

5. What event must occur and what other conditions must prevail in order for the community health worker to be active? (The community health worker must have logistical support, must be supervised and otherwise be linked to the health care system, and in the long run, must remain on post long enough to earn credibility and gain experience.)

6. What must precede these conditions? (A training program must be functioning and, it is assumed, the community itself must participate in providing incentives and motivation to the community health worker.)

7. The process of working backward is continued until a set of conditions is reached that is beyond the influence of the program managers. (This sets the boundary of the subsystem of interest.)

System models often are not linear, that is, do not move in only one direction. Many models contain feedback loops, which represent the effect of some conditions on other conditions earlier in the system. It is important for the analyst to remember that the purpose of a system model is not to serve as a perfect representation of the real world in all its complexity, but to highlight important places where conditions can be influenced so as to produce an outcome as near as possible to the statement of objectives for the system. The skill in modeling is in knowing how much detail maintains validity and how much is confusing. Bailey spoke of the "art of modeling" and ends his discussion with the admonition not to "make things more complicated than they have to be!"(2) As with any other task, skill improves with practice and with familiarity with the system.

Figure 3-1 shows the model that would correspond to the preceding narrative. There is a feedback loop that implies that more use of oral rehydration therapy by the community produces a discernible change in morbidity due to diarrhea and that this in turn causes the community to provide more incentives to stabilize the community health worker. The model terminates at the point where the national health policy determines that the country will employ community health workers and perhaps import oral rehydration salts and supply them to the health workers as part of a national campaign to promote their use at the community level.

Figure 3-2, which was shown earlier as Figure 2-2, is displayed again to demonstrate how much more detailed and complex the model might be made.

Figure 3-3 is an example of a quantified system model, which shows not only the system components in relation to one another, but also the strength with which the output of one component determines the output of the next component in the chain. This type of model gives the analyst an idea of how change in one component will affect not only directly adjacent components, but also others later in the chain.

How are these quantified relationships derived? One possibility is that data are available from previous descriptive or experimental studies. For example, it is not uncommon for price-demand functions to be derived (by survey or experimentally) for various goods and services, including medication such as oral rehydration salts. This information may have come from the population in question or from one deemed sufficiently similar to allow comfortable transfer.

When quantitative data are not available, the analyst may choose either (a) to estimate, based on experience, what values might pertain (especially if it is reasonable to use an ordinal index such as none, weak, moderate, strong), or (b) to opt for one of several techniques that are available to harness the collective judgment of a group of "experts." Two techniques, nominal group and Delphi, are discussed below.

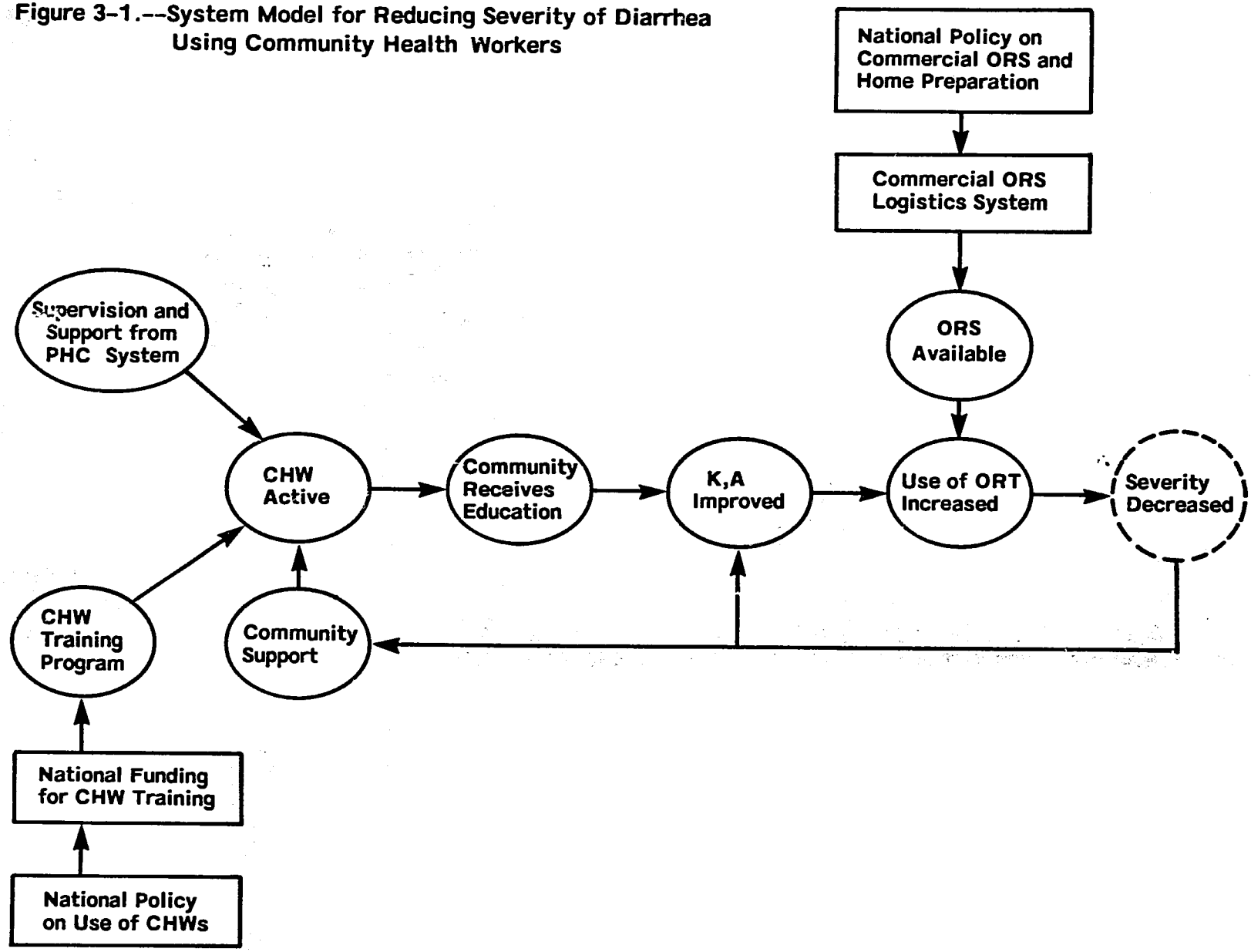
In some situations, estimation of data values by an individual or group may not be appropriate. In such cases, it may be necessary to gather specific data. For example, if a mass media campaign is planned to change knowledge, attitudes, and practices relating to oral rehydration therapy and two alternative options are under consideration, broadcast and print, a key piece of information in weighing one against the other is how many people listen to radio, watch television, or read. If the outcome of the analysis is quite sensitive to this particular point (i.e., a relatively small change in the value of the variable produces a relatively large change in the outcome of the analysis), then fairly accurate data are needed and a survey of households might be in order.

In each case, the analyst must determine what data are needed for the analysis of the operational problem--or even before that, simply to describe the system in appropriate detail--and then determine how to ensure that those data are available.

Interaction Matrices

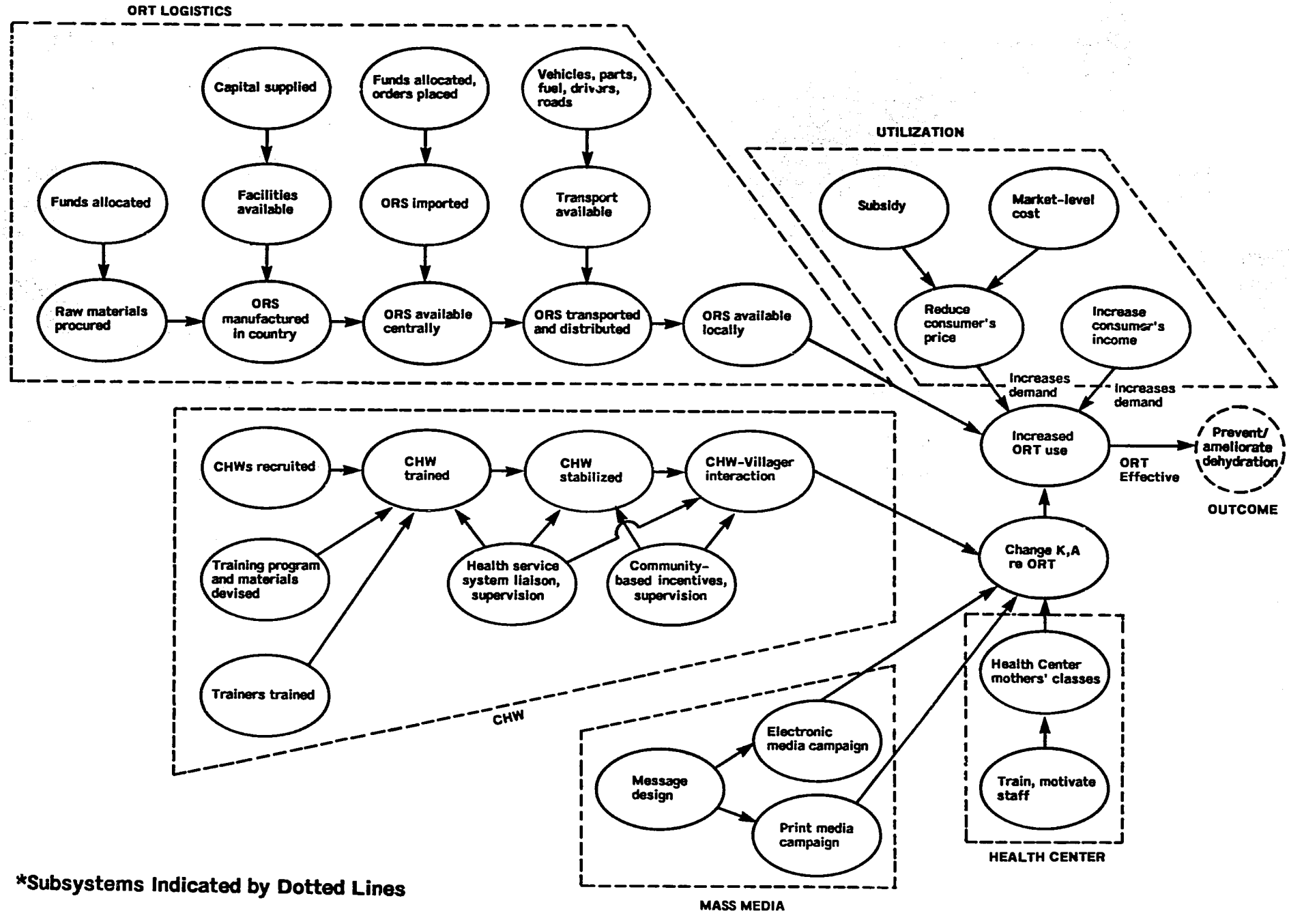
An interaction matrix is a two-dimensional array (two-way table) of two categorical sets, the components of one set being placed along one axis and the components of the second set along the other axis. At the points of intersection, the strength and significance of the relationship between each pair of elements is noted. Together, these two figures give the analyst an estimate of how improving the quality of one factor is likely to change the other member of the pair. For example, in an interaction matrix relating a community financing scheme to community characteristics, seasonality of harvest may have strong implications for scheduling of fee collection, but little for fund disbursement, and only moderate impact on financial recordkeeping.

Figure 3-1.--System Model for Reducing Severity of Diarrhea Using Community Health Workers



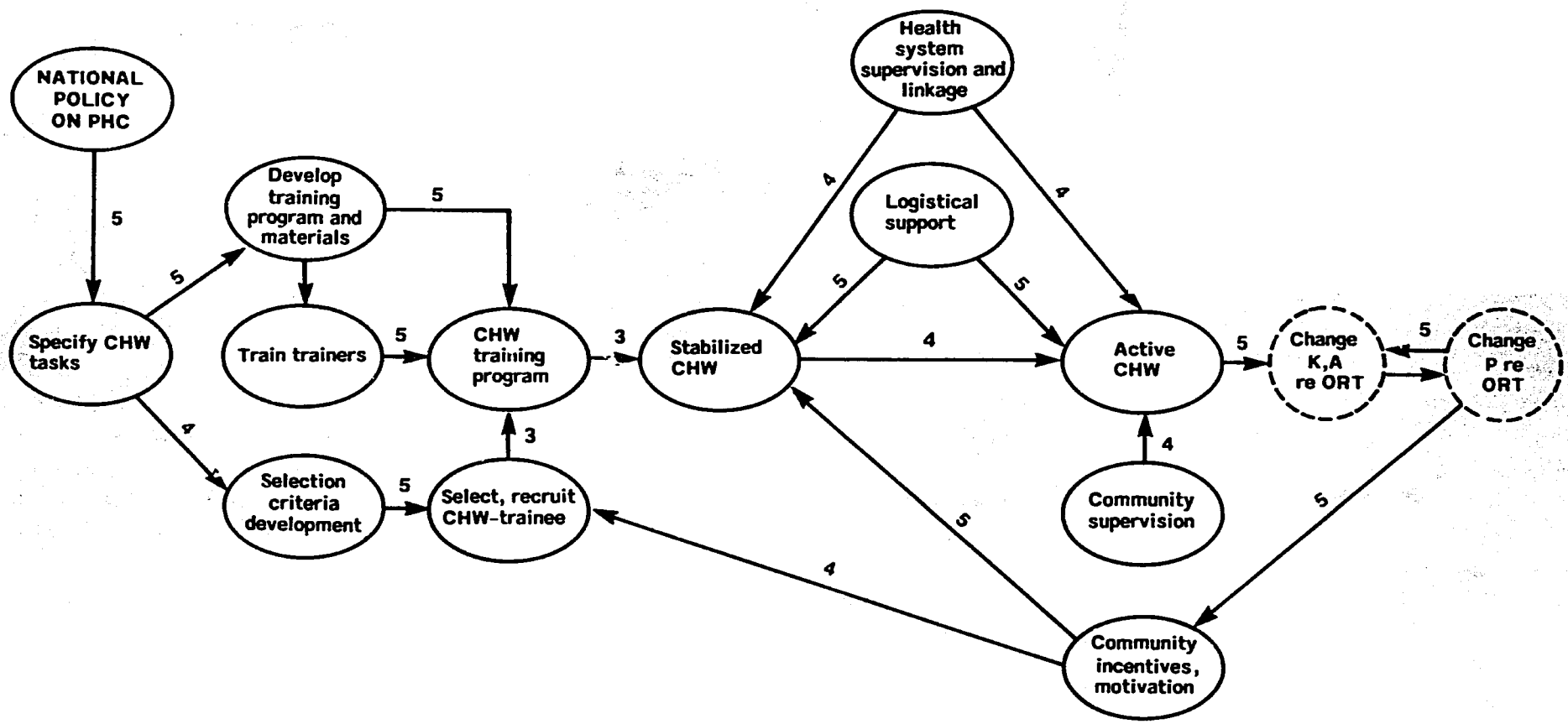
K,A= Knowledge, Attitudes Concerning ORT

Figure 3-2.--System Model for Decreasing Severity of Diarrhea by Means of Increased Use of Commercial Oral Rehydration Salts*



*Subsystems Indicated by Dotted Lines

Figure 3–3.--Quantified System Model



3,4,5 = strength of causal link

K, A, P = Knowledge, Attitude, Practice

An interaction matrix facilitates the listing of the components of a system and systematic examination for interaction between any pair of components. Interactions may be described with regard to strength, direction, and importance to the output of the system. It is also possible to examine the relationship between elements of two different systems this same way. In the problem analysis phase of operations research, interaction matrices can be used to assist in the construction of the system model, ensuring that important interactions are not overlooked. The technique is also useful for ordering priorities of research problems by helping to determine where within a system improvement might have the greatest impact on output.

Figure 3-4 shows how an interaction matrix might be used to assist in the determination of which subsystem should be treated first in the larger system shown in figure 3-2. The assumption is made that in the target population, oral rehydration therapy is being introduced. Thus, the estimation of the potential improvement at each intersection is made from a base of zero. It may be seen in this example that in terms of increasing knowledge of the effectiveness of ORT in the target population, strengthening the skills of the CHW is expected to result in very significant improvement (**b**). By contrast, improving the ORS distribution system is not expected to have much actual effect (**b**) even though it has considerable potential to do so (**a**).

An important limitation on this method is its inability to illuminate relationships between factors that are not directly related, but that are related through another factor. An example would be educational criteria for community health workers with respect to their selection and their effectiveness in service delivery. The former affects the latter, but indirectly; education helps determine characteristics of the training program, and the latter affects effectiveness. Thus, interaction matrices are not a substitute for a system model.

Logical Framework

The Logical Framework developed for the U.S. Agency for International Development is a very effective planning tool that can be used as an adjunct to, but not a replacement for, the system model.(3) Where the latter is a visualization of the important aspects of the system needed to clarify understanding, the Logical Framework (also known as a logframe) represents a preliminary plan for action. It identifies very clearly the goals and objectives of a project, the required resources, and the expected outcomes and how those relate to objectives. The one thing it lacks is a description of the actual process by which inputs will be linked to outputs.

Several versions of the Logical Framework now are available. Two are shown here. Figure 3-5 is an original version of a logframe for a PRICOR study. Figure 3-6 shows another version of the logframe as it might have been done for the same study.

A glance at the logframe format shows that it flows logically both vertically and horizontally. In filling it out, the analyst or planner may opt to work first either way; however, the vertical plane is filled from top to bottom and the horizontal, left to right. AID rightly cautions that no matter how well done, the logframe "does not assure that the approach taken is optimal," or that it "addresses the most critical constraint to goal achievement or that it is the most effective means for overcoming that critical constraint unless the planners...explore alternative approaches."(4)

Figure 3-4.--Interaction Matrix: System Objective Conditions and Subsystems Means

(Objective: Increase Use of Commercial Oral Rehydration Salts)

MEANS	CONDITIONS			
	Increase Knowledge	Improve Attitude	Increase Availability	Increase Financial Access
Strengthen CHW	5,5	5,5	2,3	0,3
Improve ORS Logistics	4,1	1,5	5,3	3,3
Reduce Price: Income Ratio	0,0	2,5	0,3	5,3

(a,b): a = power of the means to change the condition
b = expectable degree of improvement for existing condition in this case

Range: 0 = none; 5 = maximum

Figure 3-5.--Logical Framework for a PRICOR Study in Latin America

NARRATIVE SUMMARY	INDICATORS	MEANS OF VERIFICATION	IMPORTANT ASSUMPTIONS
Program/Sector Goal: Expand coverage and utilization of PHC interventions in Favela populations	Overall coverage change	Pre- and post-coverage	1. E.g., other facilities (comparable delivery systems) 2. Legal constraints (especially pharmaceuticals) 3. Religious constraints
Project Purpose: Sustain services over time through development of appropriate financing schemes	1. E.g., utilization at certain levels of cost 2. No. of additional initial visits	1. Analysis of service statistics a. unit and mini-post records 2. Costing survey findings	1. E.g., quality of recordkeeping 2. Inflation 3. Availability of information
Outputs: at certain cost levels a. No. of health care contacts/by service establishments b. No. of individuals cared for c. Level of community participation in scheme development	Output levels Levels based on a, b, c	Scheme/costs relationships (will utilization levels meet cost) Opinion surveys	1. E.g., should inform community 2. Income 3. Locations
Inputs: Services Personnel costs and mix Facility equipment and commodity costs and mix Intervention mixes	Survey findings for appropriate categories	Analysis of findings for each appropriate category	1. Availability of cost information and quality of information a. survey instruments and responses

Figure 3-6.--Expanded Logical Framework for a PRICOR Study in Latin America

PROJECT DESIGN SUMMARY
LOGICAL FRAMEWORK

NARRATIVE SUMMARY	OBJECTIVELY VERIFIABLE INDICATORS	MEANS OF VERIFICATION	IMPORTANT ASSUMPTIONS
Program or Sector Goal: The broader objective to which this project contributes: Increased accessibility of PHC services in spatial, social, and financial terms. (Longer range goal: reduced morbidity and mortality in primary target population group.)	**Measures of Goal Achievement:** Increased utilization of PHC services by targeted population segments. Long range: Change in specific morbidity/mortality rates)	Pre-/Postintervention survey of target population. (Long range: not intended for this study.)	**Assumptions About Linkage Between Project Purpose and Program Sector Goal** 1. That local financing is a vital factor in the long-term provision of effective PHC services to this population. 2. That other constraints (e.g., legal, social) are not so limiting as to preclude achievement of the goal even if a financing scheme can be created.
Project Purpose: Demonstrate that financing schemes are available which will result in a sustainable service program of acceptable quality in terms of curative, preventive, and promotive services.	**Conditions that will indicate purpose has been achieved: End of project status.** 1. Resources being generated on continuous basis 2. Resources generated at targeted level 3. PHC utilization rates at target levels 4. Probable sustainability	1. and 2. Accounts records re collection and disbursement of funds. Records of services and inkind contributions. 3. Health unit service records and census sample survey. 4. Interviews with community leaders	**Assumptions About Linkage Between Outputs and Project Purpose** 1. That the effectiveness of a financing scheme that is observed to function in the period of the research is sustainable over a much longer period. 2. That the PHC system that functions during the period of research will continue to function in a "normal," nonresearch environment.
Outputs: 1. A sustaining financing scheme 2. Functioning PHC delivery system.	**Magnitude of Outputs:** 1. Targeted resource-levels 2. Target community participation rate 3. Specific targeted rates for curative, preventive, and promotive activities within PHC system	1. Accounts records 2. Community service and inkind contribution records. 3. CHW and health unit service data.	**Assumptions About Linkage Between Inputs and Outputs** 1. That the target population will divert resources from present use to payment for PHC services (including preventive and promotive). 2. That community leadership can be found or created to oversee the operation of a financing scheme, or some other community-based mechanism can be found to accomplish this. 3. That the research staff input is adequate for this task and that resources required from outside the community will be forthcoming.
Inputs: 1. Research staff and transport 2. Service staff 3. PHC service commodities 4. PHC service facility and equipment 5. Money	**Implementation Target (Type and Quantity)** 1. 2 Principal Investigators at 1/2-time 2. 8 CHW's, 2 nurse-supervisors 3. Key commodities: (to be stated) 4. 2 standard-equipped health units 5. $40K (PRICOR), $20K (host)	1. Reimbursement submissions 2. Supervision records 3. Procurement/disbursement records 4. Observation by principal investigators. 5. Reimbursement submissions, personnel records, procurement/disbursement records.	

Nominal Group Technique also may be used to generate a list of items; for example, goals and objectives of primary health care, before rank-ordering is undertaken.

An important feature of this technique is facilitating group interaction while maintaining an environment for individual, independent judgment. A group of "experts," people whose judgment is generally recognized as sound in the area under consideration, is assembled. The moderator (often a person whose own field is group dynamics rather than the substantive subject area and who will help structure discussion but not take part in it) outlines the task and the procedure to be followed.

If the task is to rank-order a listing of items, the list is presented and each participant is asked to order the items without consulting other participants. The rank-ordered lists are collected, and the moderator displays (on a blackboard or paper flip pad) the "vote" for each item. Each item is then discussed, and each participant is able to argue for its importance relative to the others. It is important to establish a spirit of joint, rather than individual, responsibility for clarifying the meaning of any item.

A second round of independent voting takes place and the results are tallied. If the second round rank-ordering does not produce results appreciably different from the first, the process is considered to have reached closure. If there is considerable difference, the moderator should consider a third round.

When the Nominal Group Technique is used to generate the list of items to be ordered, the first step of the meeting is for each participant to produce his own list. The moderator then calls on each person in turn to offer one item for the group list, which is written on the board or pad. This process is continued until no one has any items left to offer. During this idea-generating phase, no discussion is allowed. Individuals should try to avoid obvious duplication, but no one's judgment is questioned during the list-generation procedure. When the listing is complete, discussion is encouraged to consolidate the list and eliminate duplication, but not ideas. The ordering process described above then begins.

The decision rule in every vote is the group mean. Other decision rules (majority rule, mode rule) have been studied, but the mean has been shown to be the most accurate indicator of group preference.(5)

The research-oriented reader will be familiar with other judgment scaling techniques, for example, Thurstone and Edwards scales. These, however, are designed to create an index variable from a set of several variables that are thought to be measures of the same phenomenon. An example would be a survey of attitudes toward various kinds of health services (e.g., immunization, prenatal care, weaning, or contraception) in order to produce an index of "innovativeness." Nominal Group Technique, by contrast, can be used to order unrelated items, and in addition, to generate the list itself.

Delphi

The Delphi technique is another means for bringing collective judgment to bear on questions that are basically subjective and value-laden; that is, where the level of the response--very important, fairly important, unimportant; high, medium, low; excellent, good, fair, poor; yes, no--is dependent upon a subjective point of view. In addition, Delphi may be used initially to generate an initial list of responses to a broad question, which will then be evaluated and rank-ordered by the group. For example, as a first step toward determining an effective financing scheme for primary health care, the group may be asked simply to list the pros and cons of community financing versus central government financing.

The following explanation of terms and data used in figure 3-6 serve as a guide for preparing a logframe. Under the heading Narrative Summary are entered:

Program/Sector Goal: In this case, the sector is health (as opposed to education, agriculture, industrial development, and so on). The program is primary health care (as opposed to hospital construction, medical education, central administration, and so on). The goal is enhanced effectiveness of primary health care services.

Project (Study) Purpose: This is the desired outcome(s) of the study which, assuming it occurs, will advance the societal condition toward the goal. In the systems terms used earlier, these are the objectives that sum up to achievement of the goal.

Outputs: These are the things that happen as a direct result of the actions taken in the study or, in systems terms, as a result of the "process." For example, the output of a CHW training program is a given number of community health workers trained. In addition to planned outputs, managers must also be alert to unplanned outputs. A CHW training program might result not only in trained health workers, but also in greater community interest in other aspects of health service. Or, an unplanned output might be a decrease in felt responsibility for health by the community in general as a result of having more trained health workers there.

Inputs: These are the human, material, and fiscal resources that must be employed in the process of obtaining the desired outputs.

Objectively Verifiable Indicators: quantifiable measures of input, output, and objectives; for example, number of training staff, number of villagers, training costs, number of community health workers trained, number of CHW-villager interactions.

Means of Verification: refers to the means by which the indicators data will be obtained.

Important Assumptions: known or expected causal linkages between inputs to the system, system outputs, and achievement of objectives.

Nominal Group Technique

Nominal Group Technique is a group decision technique used to apply group judgment to problems that are highly value-laden; that is, to which responses are subjective rather than objective. The technique is often used to rank-order a list of items. For example, given a list of goals that can not all be attained at the same time, a decision would have to be made as to priority. Such a decision might deal with whether to direct most available resources first toward reducing infant mortality, toward reducing child mortality, reducing maternal mortality, or reducing disability among productive workers. One person could make these judgments, but a group probably has a better chance of being "right" for that society. Moreover, if appropriate decisionmakers are included in the group, a certain amount of concurrence in the outcome of the research is established from the beginning.

Under solution development, we mentioned the possibility of estimating parameters using Nominal Group Technique when actual measurements are not available. For example, it may be necessary to estimate the effect of each item in a set of constraints (such as climate, available transportation, level of education, and cultural tendencies) on several possible strategies to immunize children in order to determine which strategy would be most likely to work best.

(objective weight and level of achievement with that strategy), and the utility summed for each strategy. Figure 3-7 shows a hypothetical example for three strategies and a complex of six objectives. Based on the weighted values of the objectives and the effectiveness of each strategy in achieving each objective, the analysis shows that the CHW training strategy has a higher utility than the other two.

In the example, imaginary values are used to illustrate the methodology. Obviously, a key task in carrying out this analysis is the assignment of a realistic weight to each objective and determination of levels of effectiveness. These are obtained by graphing a utility function, which shows the relationship between utility (rated from 0 percent, totally unsatisfactory, to 100 percent, completely satisfactory) and different levels of achievement of each objective.

As an example, figure 3-8 shows utility functions for the objectives (a) "Bring curative services within 5 kilometers of 90 percent of the provincial population" and (b) "95 percent of infants receive the full complement of immunization by age 1." Complete achievement of the objective is rated at 100-percent utility. It is not necessary to equate zero achievement of the objective with 0-percent utility; a floor may be set below which any achievement is completely useless. Note that the relationship between proportion of objective achieved and percent utility is not necessarily linear.

Calculation of the level of effectiveness of a strategy for achieving a particular objective may or may not be fairly straightforward. Determining percentage of target population brought within n kilometers of a service point under different strategies is not difficult. Determining the percentage of population that would live in villages where sanitation goals would be met could be less certain, requiring a mixture of straight calculation of villages that could be reached and some estimate of how people would behave.

Determination of utility, however, is usually much more an exercise in subjective judgment. Although it is true that in some cases objective guidelines are available (for example, the epidemiologic principle of a critical mass of immune persons needed to suppress an epidemic), in many cases the relative value of x-percent achievement of an objective versus y-percent achievement is quite subjective. In such a case, managers or analysts may opt to use their own judgment in the creation of utility functions, or they may decide that one of the group techniques is needed. The weight given to each objective is almost certainly a subjective judgment and, as such, is most amenable to being set by means of a group technique such as nominal group.

Two additional points should be made. First, the usefulness of multiple-criteria utility assessment as an analytic tool can be enhanced by combining it with cost-effectiveness analysis (see below) when the proposed strategies each have a different cost attached to them. The implication is that money is not the limiting factor in each strategy, but some other resource or consideration. If, for example, the CHW training program had an associated cost of $95,000, the health center multiplication $75,000, and the improved transportation $80,000, then the cost-effectiveness indexes would be, respectively, 76/95000, 61/75000, and 67/80000, or .80, .81 and .84 (each x 10^3). Now, the transportation option appears more attractive than either of the others.

The second point is a repeat of one made in the discussion of solution development in chapter II; namely, that the sensitivity of the analysis must be considered. How much would the outcome of the analysis change if the strategy weights and the effectiveness estimates were modified? What implications does uncertainty, either in objective weighting or strategy effectiveness, have for strategy selection?

In contrast to the Nominal Group Technique, Delphi groups do not ever meet together for discussion; each participant fills in questionnaires without any communication with the other members of the group. The first questionnaire may be very general, especially if it is intended to generate a list of responses that will be evaluated, culled, and ordered by the group. On each succeeding questionnaire, the range of permissible responses is narrowed based on the same averaging technique as is used for nominal group. The iterative process is halted after several rounds, and the final collective ranking of responses is taken as the group's judgment.

It is the repeated surveying of the group on a continuously shrinking set of permissible responses that differentiates Delphi from an ordinary one-time survey with an averaging of respondents' answers. Delbecq, et al., point out that Delphi should not be used if there is not adequate time for repeated surveying of the participants, or if the participants do not have strong written communications skills or do not have strong motivation to complete the entire process.

The analyst should always think twice when considering Delphi as an alternative to the Nominal Group Technique. There is little the former can do that the latter cannot, and the Nominal Group Technique does have the advantage of speed and the benefits that accrue from group interaction. The place for Delphi is where the "experts" simply cannot be assembled in the same room, perhaps for reasons of geographic dispersal or inconvenient timing.

TECHNIQUES WITH APPLICATION TO SOLUTION DEVELOPMENT

Interaction Matrices

Interaction matrices can be used in the solution development phase to reveal the constraints and facilitating factors on decision variables. For example, a transport network whose carrying capacity varies seasonally has major implications for manpower development programs, for commodity supply and local storage, for management information systems, and for central supervision, but not necessarily for local supervision, money collection, or recordkeeping.

Multiple-Criteria Utility Assessment

Multiple-criteria utility assessment allows the decisionmaker to select one strategy from among several alternatives when more than one objective is involved and each strategy is expected to affect each objective with a different degree of effectiveness. The technique also allows consideration of each objective at a different level of importance.

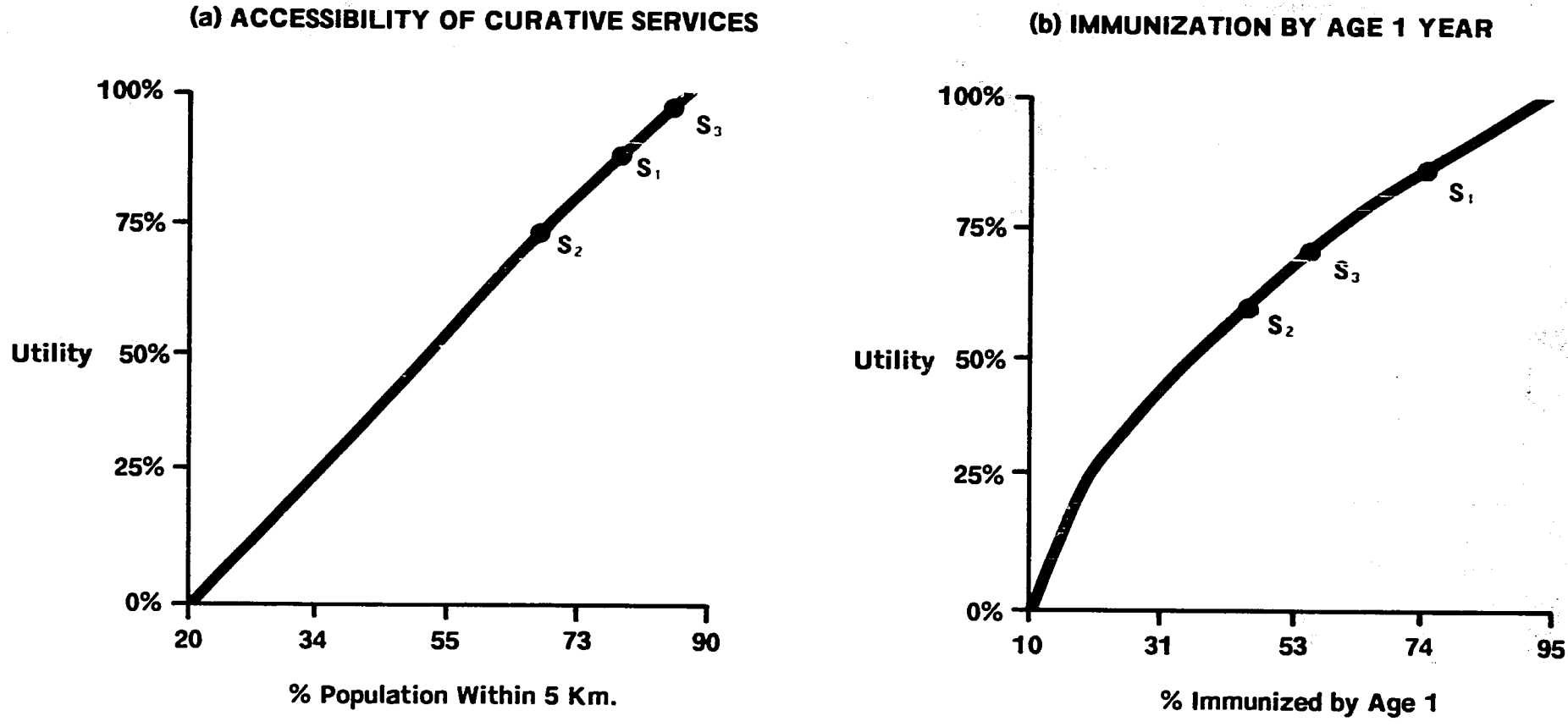
The method starts with a listing of the objectives to be accomplished. These become the criteria by which each alternative strategy will be judged. Next, a weight is assigned to each objective, which designates the relative importance of each. The most important is given a weight of 1.0 and the others less. This scaling is not simple rank-ordering, but assignment of weight on an interval scale ranging from 1.0 (of the highest importance) to 0 (completely unimportant); the implication is that a weight of 0.75 means three-quarters as important as the objective with weight 1.0; 0.5, half as important, and so on. The same value may be used more than once; it is even conceivable that all the objectives could be judged equally valuable and given a weight of 1.0.

After the objectives and their weights are stipulated, potential strategies for reaching these objectives are posed, and each strategy is evaluated in terms of how well it could achieve each objective. The utility of each strategy-objective pair is calculated

Figure 3-7.--Multiple-Criteria Utility Assessment for Primary Health Care Objectives and Means

		UTILITY VALUES		
OBJECTIVE	WEIGHT	Train CHWs	25% More Health Centers	Improve Transport to Present Centers
% Accessible to Effective Curative Services	1.0	80%	70%	90%
% Under-Fives Immunized	1.0	85%	60%	70%
% Sanitation Goals Met	0.8	75%	40%	30%
% Under-Fives Monitored for Nutrition Status	0.9	95%	75%	80%
% Severe Diarrhea Treated With ORT	0.9	80%	75%	75%
Family Planning Acceptance Rate	0.7	30%	40%	45%
UTILITY	5.3	4.04/5.3 = 76%	3.25/5.3 = 61%	3.55/5.3 = 67%

Figure 3-8.--Two Examples of Utility Functions



Strategy 1: Access = 78%, Utility = 80%
Strategy 2: Access = 69%, Utility = 70%
Strategy 3: Access = 86%, Utility = 90%

Strategy 1: Immunized = 76%, Utility = 85%
Strategy 2: Immunized = 49%, Utility = 60%
Strategy 3: Immunized = 56%, Utility = 70%

Cost-Effectiveness Analysis

Cost-effectiveness analysis was discussed briefly in the listing of operations research techniques developed for industrial applications in the model identification section of chapter II. This discussion also pointed out the distinction between cost-effectiveness analysis and cost-benefit analysis. Because it is so important and widely applied an analytic tool, cost-effectiveness analysis warrants further discussion. Because cost-effectiveness analysis has many applications in many different fields, it has been widely described in general references, either as chapters in management texts or as separate monographs and books. One monograph aimed specifically at health applications is the PRICOR companion monograph to this paper, Operations Research Methods: Cost-Effectiveness Analysis, by Jack Reynolds and Celeste Gaspari.(6)

Cost-effectiveness is a measure of efficiency; that is, an accounting of how much output a system produces for each unit of input resource--in this case, a very important and often limiting resource: money. The outcome of the analysis is shown as the ratio of cost per unit of effectiveness. Cost-effectiveness analysis permits the analyst to compare the relative efficiency of different approaches to the same objective from either the viewpoint of maximizing the output obtained from a fixed level of resources or obtaining a fixed level of the objective with a minimum of expended resources.

Effectiveness may be defined any way that is convenient and sensible to the problem at hand, whether it be process, output, or outcome. For example, number of community health workers trained, number of children immunized, number of patient contacts, couple-years of contraceptive use, number of ponds sprayed with larvicide, number of latrines constructed, percent reduction in age-specific mortality or in disease-specific morbidity, disability-days averted, or percent reduction in age-specific birth rate all may be used as measures of the effectiveness of a program, depending upon its purpose, even though some are process measurements, some output, and some outcome.

By contrast, the analyst has less flexibility in defining costs during the course of the analysis. It is important that all costs be accounted for, and to assist in this task, certain cost-category frameworks have become conventional. Thus, costs are examined as direct or indirect, as recurrent or capital, and as fixed or variable.

Direct costs are those that are clearly and immediately attributable to the program in question; good examples are the salaries of staff involved and the costs of materials consumed in the program. Indirect costs are the costs of those services without which the program could not function, but which provide service not only to the activity of interest but also to other activities whose own direct cost must be shared proportionately by all the activities or programs they support. An example would be staff who provide administrative services at an organizational level above that of the activity being costed.

Recurrent costs are those that pay for items that are fully consumed in a relatively short time-frame, usually one budget cycle; salaries and supplies are examples. Capital cost items are those whose usable life extends over more than one budget cycle and whose cost is amortized (distributed for accounting purposes) over a longer period of time, often the lifespan of the item; for example, buildings and vehicles.

Finally, costs may be categorized as fixed or variable. Fixed costs are those that do not vary as the output of the program varies. If a health team comprising several different kinds of staff is needed to provide a full complement of services, and if the team can serve up to 20,000 patients a year, then for any patient load less than that number, the cost of the health team is fixed. By contrast, the materials used to treat the patients do vary directly with the number seen and thus represent a variable cost.

Aggregation of total cost requires accounting for the potential costs of goods and services that are received free, but that are vital to the activity. Voluntary labor and donated drugs are perhaps the the most common such items. The estimated values of these are called shadow prices and must be included in the costing process.

Once program costs have been developed and measures of effectiveness determined, the ratio of cost-per-unit effectiveness is calculated; for example, $x per community health worker trained, $y per child immunized, $z per 1-percent reduction in infant mortality. Cost-effectiveness analysis is often done retrospectively, using carefully recorded cost and effectiveness data. In this way, the technique may be used to evaluate the outcome of a field trial of one approach against some fixed constraint (e.g., "cost of this program must be less than 10 cents per immunized child") or two or more approaches to the same target objective. Thus, cost-effectiveness analysis can be a valuable tool in the solution validation phase of an operations research analysis.

Cost-effectiveness analysis also can be used as an important prospective decision tool for operations research if costs and effectiveness can reasonably be estimated. For example, suppose that a program to train community health workers can be carried out in either of two ways. The first approach, in which the training team comes to a centrally located village and remains for one week to train local community representatives, requires a vehicle and per diem for the trainers and is estimated to cost $1,000 per month. It is expected that in that month 40 CHWs can be trained, for a cost of $25 per CHW trained. The second approach would pay for village representatives to come to a district health center and spend one week in training. The program would pay for their transportation to and from the health center and would provide meals. As the training staff is based at the health center, no per diem is required and no vehicle is allocated for use of the program. The estimated cost for one month is $600 and the number of CHWs expected to come for training is 8 per cycle, or 32 in the month. Assuming all other training costs (e.g., materials) are the same, then the second program would be the more cost-effective because it would cost only $18.75 per CHW trained.

It is reasonable to expect good approximation of effectiveness when the unit of measure is a process type of output measure, such as number of community health workers trained, number of children immunized, or patients seen. Much less certain would be true outcome measures, such as changes in morbidity or mortality or number of couples accepting family planning.

Any comparisons that are done must use a common denominator. One could not compare directly, for example, a program that results in a cost of 10 cents per immunized child and another that results in a cost of 20 cents per child monitored for growth (although it may be possible to convert both to a third, common denominator such as "child deaths averted").

Finally, a given amount of money does not have the same value at all times. The purchasing power of $x will not be the same one year from now as it is today. Two forces are at work to account for this: inflation, which devalues a fixed amount of money over a period of time, and the so-called opportunity cost, that is, the fact that money in hand can be invested to produce more money, even if only through simple interest.

Thus in real terms, a project that costs $100,000 in one year does not really have the same cost as one that consumes $100,000 over a 4-year period. Therefore, it cannot simply be assumed that if two such projects were to be compared on a cost-effectiveness basis, the numerators could be equated and only the denominator compared. The differential value of money over time is dealt with by the use of a discount rate, which

represents the rate of inflation and the investment value of the money combined in a way that converts aggregated future expenditure into its current value. For a discussion of this subject, called Net Present Value, the reader is referred to the PRICOR methodology paper on cost-effectiveness analysis by Reynolds and Gaspari .(6)

Decision Trees

Decision trees enable the analyst to examine the probable outcome of a sequence of decisions which are affected by intervening uncontrollable events. By assigning probabilities to the occurrence of these events, the analyst can determine in advance what combination of decisions offers the highest probability of achieving a stipulated objective.

The technique begins with the construction of a model showing the sequence and interaction of decisions and uncontrollable events, usually in chronological order. The first item in the model represents the first decision that must be made. From this decision point, or node, tracks are drawn to represent the alternative choices of action that might be taken. All choices must be accounted for, and they must be mutually exclusive, that is to say, it must be possible to take only one of these actions at one time. Next, the chance (i.e., uncontrollable) event is shown on each track and new tracks are drawn leading out from these nodes to represent the state of affairs following this occurrence. In addition, a probability is assigned to the occurrence of each of these uncontrollable events. The usefulness of this method is greatly dependent upon the accuracy with which these probabilities can be assigned.

This branching sequence of decisions and chance events continues until all are accounted for in the model. (It may be seen that the model can become quite complicated very quickly as the number of decision points and chance events increases. Hand calculation of the output may be impractical if more than a few events and action decisions are involved.)

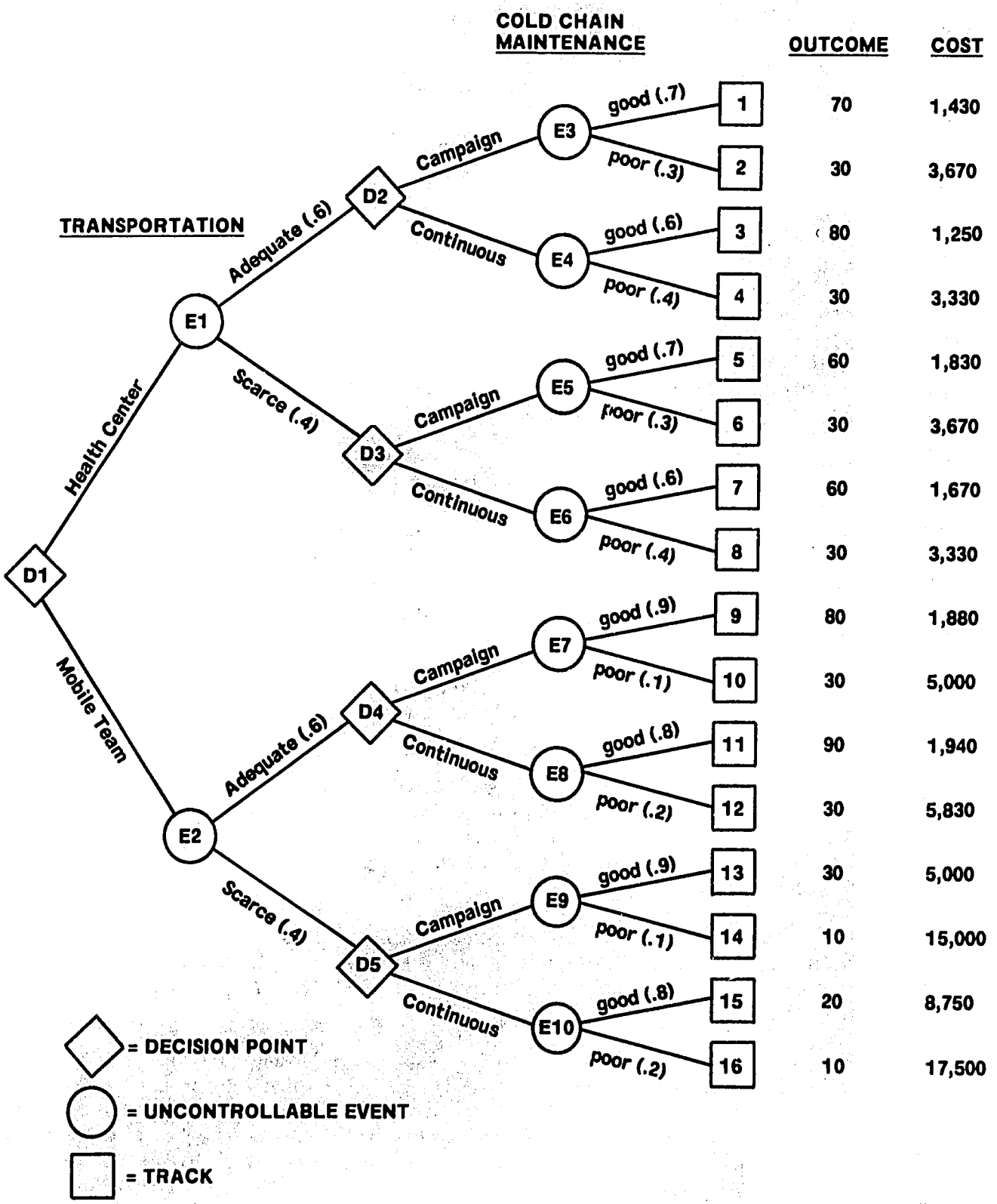
Finally, at the end of each branch is placed an estimate of its outcome stated in terms of the objective sought for the sequence of decisions.

For both chance event probabilities and outcomes, values may be known fairly accurately from previous experience. If not, it will be necessary to employ estimates made by one knowledgeable individual or through a group process. For example, meteorological records may be available for such events as time of onset and severity of the rainy season, and previous immunization programs may yield information on expectable outcomes of certain approaches.

Figure 3-9 shows a decision tree for a program aimed at immunizing a particular group of children within a prescribed period of time. Diamonds, labeled "D", represent points at which a decision must be made; circles, labeled "E", represent the occurrence of uncontrollable events.

Program planners must decide whether to use a mobile team for this purpose or to use the rural health centers (it is assumed that the decision must be one or the other and not some combination) and whether to mount a one-shot campaign at some time in the period or to establish a continuous service for the period available. Since the country experiences occasional shortages of petrol, transportation required to support this immunization effort may be adequate or it may be scarce enough to constitute a definite problem. The planners have no way of knowing what the situation will be at the time the program is ready to start, but are able to assign probabilities based on the last few years; these are shown on the appropriate track in the model. They also know that in past

Figure 3-9.--Decision Tree for Immunization Program



OUTCOME = PERCENT OF TARGET CHILDREN EFFECTIVELY IMMUNIZED; COST PER 1% OF OUTCOME

programs problems have arisen with maintaining the cold chain, and they estimate that there is a significant chance that the chain will break down. Estimated probabilities of these uncontrollable events are shown along the appropriate branch.

At the end of each track is shown an estimate of the outcome of that sequence of actions and events. For example, it is estimated that if the focus of the program is the health centers, if transportation turns out to be adequate, if a campaign approach is adopted, and if the cold chain holds up (track 1), then it is reasonable to expect that 70 percent of the target children will be effectively immunized. On the other hand, if a mobile team approach were taken, transportation turned out to be inadequate and a decision were to be made to use what is available on a continuous rather than a one-shot basis, and moreover the cold chain did not hold up well (track 16), then only 10 percent of the target is likely to be achieved. Note that, in the planners' estimation, inadequate transportation would have more impact on the outcome of a mobile-based program than on one focusing on the health centers. Also, as may be seen, the probability that the cold chain will be maintained properly is different not only between the health center and the mobile team, but also between the campaign and continuous approach. This is due to the longer period of the latter and consequent greater chance of some part of the system breaking down. It is important to note that the probability of a particular sequence of decisions and events occurring is not taken into account in estimating outcome, only what that outcome is likely to be if that sequence does occur.

In the first analysis, the planners' objective is assumed to be to maximize the percentage of target population immunized. The computations required to determine a best strategy proceed "backward" from the last event or decision in each chain toward the first. For example, assuming that the program is based in the health centers, that transportation is adequate, and that a campaign approach were selected, then the expected payoff (defined as outcome taking into account the probability of the occurrence of that particular combination of events and decision actions) is:

$$(0.7)(70) + (0.3)(30) = 58$$

If, instead of a campaign approach, a continuous approach were selected, the expected payoff would be:

$$(0.6)(80) + (0.4)(30) = 60$$

Since the latter has a larger payoff, the planners would select that approach if they have already reached that point in the decision sequence. Decision node D2 is then said to have a payoff value of 60 because a strategy exists to yield that much payoff.

Note that the 60 percent immunization rate is simply regarded as an indicator of the better average gamble in the face of the uncertainty about how well the cold chain will be maintained. The actual outcome expected is still either 80 percent if the cold chain holds up or 30 percent if it breaks down.

If, however, having chosen the health center approach, transportation turns out to be inadequate, then the planners' attention shifts to decision node D3. Potential payoffs for D3 are:

$$(0.7)(60) + (0.3)(30) = 51$$
$$(0.6)(60) + (0.4)(30) = 48$$

Thus, a campaign approach is the better choice under these circumstances, and D3 has an expected payoff of 51.

In order to determine D1, the decision to use either the health centers or mobile teams, it is necessary to calculate the expected payoffs for D4 and D5. These are 78 and 28, respectively. Payoff values then are:

$$(0.6)(60) + (0.4)(51) = 56.4$$
$$(0.6)(78) + (0.4)(28) = 58.0$$

Thus, the strategy would be to plan for a mobile team approach initially and if, at the time the teams were ready to begin transportation was adequate, to employ them in a continuous mode (payoff value 78 versus 75 for campaign). If, however, transportation turned out be inadequate, the teams would be employed in a campaign mode (payoff value 28 versus 18 for continuous).

The realities of planning an immunization program may require that both decisions--center versus mobile, campaign versus continuous--be made simultaneously rather than sequentially. To do this, the same model can be used or a new one can be designed in which the second decision branches directly from the first and the uncontrollable activities branch out from these second level decisions until a track is created for every combination of decisions and uncontrollable events.

Using the existing model, each strategy can be traced and the expected payoff calculated. For example, for the combination of health center and campaign mode the calculation would involve tracks 1, 2, 5, and 6, as follows:

$$0.6[(0.7)(70) + (0.3)(30)] + 0.4[(0.7)(60) + (0.3)(30)] = 55.2$$

Health center and continuous mode (tracks 3, 4, 7, and 8) yields an expected payoff also of 55.2; mobile team in a campaign mode (tracks 9, 10, 13, and 14), 56.2; and mobile team in continuous mode (tracks 11, 12, 15, and 16), 54.0. Thus, the strategy selected would be to plan for mobile teams in the campaign mode. To repeat, however, the percentage of children successfully immunized is expected to be 80, 30, 30, or 10, depending upon how the uncontrollable circumstances actually turn out. It should be noted, in fact, that decision criteria other than maximum expected payoff could be employed by the decisionmaker which take into account perceived utilities of outcome. For example, the selection of one of the health center strategies would mean that the percentage of children immunized would not be expected to be less than 30 percent even if transportation proved inadequate and the cold chain broke down.

Figure 3-9 also shows outcome as cost per one percent of target achieved based on the following hypothetical costs for carrying out each of the four strategies to achieve 100 percent of the objective:

health center/campaign:	$110,000
health center/continuous:	100,000
mobile team/campaign:	150,000
mobile team/continuous:	175,000

The same calculating procedures would be used as before, except that now the objective would be to minimize the expected cost. Using the sequential decision strategy to determine the value of D2, we have:

$$(0.7)(1430) + (0.3)(3670) = 2102$$
$$(0.6)(1250) + (0.4)(3330) = 2082$$

Thus, decision node D2 has a value of 2082. D3 would have a calculated value of 2334; D4, 2192; and D5, 6000. D1 would then be calculated by:

$$(0.6)(2082) + (0.4)(2334) = 2183$$
$$(0.6)(2192) + (0.4)(6000) = 3715$$

The strategy decision, then, would be to start first with a health center focus and to use a continuous mode no matter how the transportation situation turned out because the values of D2 and D3 come from their continuous mode tracks.

If both components of the strategy must be determined simultaneously, calculations are made as before and the selected strategy is to focus on the health centers using continuous mode.

Clearly, the outcome of decision tree analysis depends heavily upon the estimates made for the outcomes of the various strategy combinations and the probabilities assigned to uncontrollable events. It is important, therefore, for the analyst to perform a sensitivity analysis to determine how small changes in these estimates would affect the result. Moreover, for the decisionmaker, factors other than those placed in the model may also be important considerations in the final selection of strategy. For instance, if the decision whether to focus an immunization program on health centers or on mobile teams is very close in the analysis, the former may be chosen because the decisionmaker may think it useful for the total health program to get the population more used to attending the health center for preventive activities.

NOTES

1. Peter Delp, et al., Systems Tools for Project Planning (Bloomington, IN: International Development Institute, Indiana University, 1977).

2. Norman Bailey, Mathematics, Statistics, and Systems for Health (New York: Wiley, 1977).

3. L. Rosenberg and M. Hageboeck, "Management Technology and the Developing World," in M. Cuenod and S. Kahne, eds., Systems Approaches to Developing Countries (proceedings of a symposium sponsored by the International Federation of Automatic Control and the International Federation of Operational Research Societies at Algiers, May 28-31, 1973).

4. The Logical Framework--Modification Based on Experience (Washington, DC: AID Bureau for Program and Policy Coordination, Program Methods and Evaluation Division, undated).

5. Andre Delbecq, Andrew Van de Ven, and David Gustafson, Group Techniques for Program Planning (Glenview, IL: Scott, Foresman, 1975).

6. Jack Reynolds and K. Celeste Gaspari , Operations Research Methods: Cost-Effectiveness Analysis (Chevy Chase, MD: PRICOR, 1985).

APPENDIX

APPENDIX: OPERATIONS RESEARCH TECHNIQUES USED BY 40 PRICOR STUDIES

Technique	Number of Studies Using Technique
System Modeling	15
Cost-Effectiveness Analysis	14
Delphi	7
Brainstorming	5
Nominal Group Technique	5
Interaction Matrix	5
Multiple-Criteria Utility Assessment	4
Regression Forecasting	4
Critical Path	4
System Definition Matrix	2
Oval Diagram	2
Goal Programming	1
Logical Framework	1
Tree Diagram	1

GLOSSARY

This glossary was compiled to aid the reader in understanding the meaning given to certain terms used by PRICOR.

ALTERNATIVE: An opportunity for choice between two or more solutions, one of which--but not more than one--may be chosen.

COMMUNITY: A group of people having common organization or interest or living in the same place under the same laws.

COMMUNITY FINANCING OF PHC: The mobilization of resources by a community to support, in full or in part, basic preventive and curative health services for its members.

COMMUNITY HEALTH WORKER: A person indigenous to the community who provides basic preventive and curative health services to members of the community. Also called village health workers. These include promotors, community health auxiliaries, health agents, health guides, health visitors, among others.

COMMUNITY ORGANIZATION FOR PHC: The processes or structures for achieving community participation in primary health care.

COMMUNITY PARTICIPATION: The involvement of community members in the planning or implementation of community activities.

COMPONENT: A part of a system.

CONSTRAINT: A requirement or restriction on a system that reduces the freedom of decision.

CONTROLLABLE FACTORS: (See decision variables.)

COST-EFFECTIVENESS: A technique for comparing the costs and the effectiveness of alternative ways of achieving the same objective.

CRITERION: A characteristic, rule, or test by which an object or event is judged.

DECISION: The act or process of choosing among alternatives.

DECISION VARIABLE: A variable in a decision problem that can be controlled by the decisionmaker.

DEMAND: The type and quantity of service or commodity wanted or requested.

DEPENDENT VARIABLE: The variable being predicted or explained (the "effect" in a cause-effect relationship).

EFFECTIVENESS: The degree to which program or system objectives are achieved. Usually, outcomes are compared to some standard, such as the objectives that were set originally. For example, the program reached 90 percent of its target.

EFFECTS: The changes in knowledge, attitudes, and behavior (practices) among individuals, families, or communities as a result of a program, project, or activity.

EFFICIENCY: The achievement of objectives without wasting resources; the relationship of output to input. For example, in two programs that use the same amount of resources, program A, which screens 10 mothers/day, is more efficient than program B, which screens 5 mothers/day.

EVALUATION: A judgment of worth. In practice, a process for making judgments about selected objects, processes, or programs by comparing them to specific value standards (e.g., objectives) for the purpose of deciding among alternatives.

FACILITATING FACTOR: An uncontrollable factor that favors certain choices (e.g., people's willingness to pay for primary health care).

GOAL: A desired effect. In primary health care, a state of health that is desired or expected to be achieved through an activity, project, or program; for example, to reduce infant mortality.

IMPACT: A change in the status (e.g., health, standard of living) of individuals, families, or communities as a result of goals achieved by a program, project, or activity. For example, a reduction in infant mortality achieved by reducing the effects of severe diarrhea by means of a program of oral rehydration therapy.

INDEPENDENT VARIABLE: A variable that is used for predicting or explaining other (dependent) variables (the "cause" in a cause-effect relationship).

INDICATOR: An observable phenomenon that is substituted for a less observable phenomenon (e.g., weight according to age in a child as an indicator of health/nutritional status).

INPUT: The types and quantities of resources (labor, money, material, etc.) used in a program, project, or activity; sometimes called effort.

INTERVENTION: In health, an activity aimed at modifying a train of events so as to produce a more desirable outcome. For example, measles vaccination is an immunologic intervention between virus and host.

MATRIX: A mathematical or graphical representation in two dimensions of the relationship between a number of variables.

MEASURE: A number assigned to an object or event. Measures can be expressed as counts (45 visits), rates (10 visits/day), proportions (45 primary health care total visits/380 total visits = .118), percentages (12 percent of the visits made) or ratios (45 visits/4 CHWs = 11.25).

MODEL: A simplified representation of the real world. In operations research, models are usually graphic (maps, diagrams, flowcharts) or mathematical (formulas, equations).

OBJECTIVE: An effect that is desired or expected to be achieved by an activity, project, or program (e.g., to increase the use of growth charts by 50 percent).

OBJECTIVE FUNCTION: A statement of the characteristics of an acceptable solution, usually expressed in quantified terms; for example, maximize the number of children that can be immunized with a particular program budget.

OPERATIONAL PROBLEM: A specific question, issue, or dysfunction in an operating system that limits the attainment of system objectives. It is a problem within the operating system as opposed to an environmental, health, or other nonsystem problem.

OPERATIONS (or OPERATIONAL) RESEARCH (OR): The application of science to the solution of managerial and administrative problems; a systematic, problemsolving process consisting of three phases: problem analysis, development of solutions, and testing of those solutions.

OPTIMIZE: To operate a system so that the system criterion is at its optimum value. For example, to minimize costs or maximize utilization.

OPTIMUM: The best, or more favorable, value that can be achieved given the constraints.

OPTION: An opportunity for choice between two or more courses of action.

OUTCOME: The results of a program or activity, usually its effects or impact, but may also include outputs.

OUTPUT: The types and quantities of goods and services produced by an activity, project, or program. For example, 750 packages of oral rehydration salts distributed.

PARAMETER: In an objective function, terms that indicate how decision variables relate to, or affect, output or outcome variables. For example, the number of children who can be immunized per day by one field worker.

PRIMARY HEALTH CARE: A strategy for making basic health services universally accessible to the world's population.

PROBLEM: (See operational problem.)

PROCEDURE: A series of predetermined tasks or actions to carry out an operation, such as a physical examination.

PROCESS: A linked series of actions or operations that are directed to a specific purpose, such as a health education session.

PROGRAM: A set of organized activities designed to reach a goal.

SENSITIVITY ANALYSIS: An analysis that shows how a solution is affected by changes in one or more of the variables that influence it.

SUBSYSTEM: A system within a larger system.

SYSTEM: A set of discrete, but interdependent, components designed to achieve a set of goals.

SYSTEMATIC ANALYSIS: Analysis carried out following orderly procedures.

SYSTEMIC ANALYSIS: The identification of the components that make up a system and an assessment of their interrelationships.

SYSTEMS ANALYSIS: A generic term to cover the application of a wide spectrum of methods (including OR) to problems or entities that are conceptualized or modeled in the form of systems.

UNCONTROLLABLE FACTORS: Factors that are not under the control of the decisionmaker.

VALUE: Estimated or assessed worth; in OR, the number assigned to a decision variable, such as the price set for ORS packages.

VARIABLES: The factors of a decision problem whose value may change.