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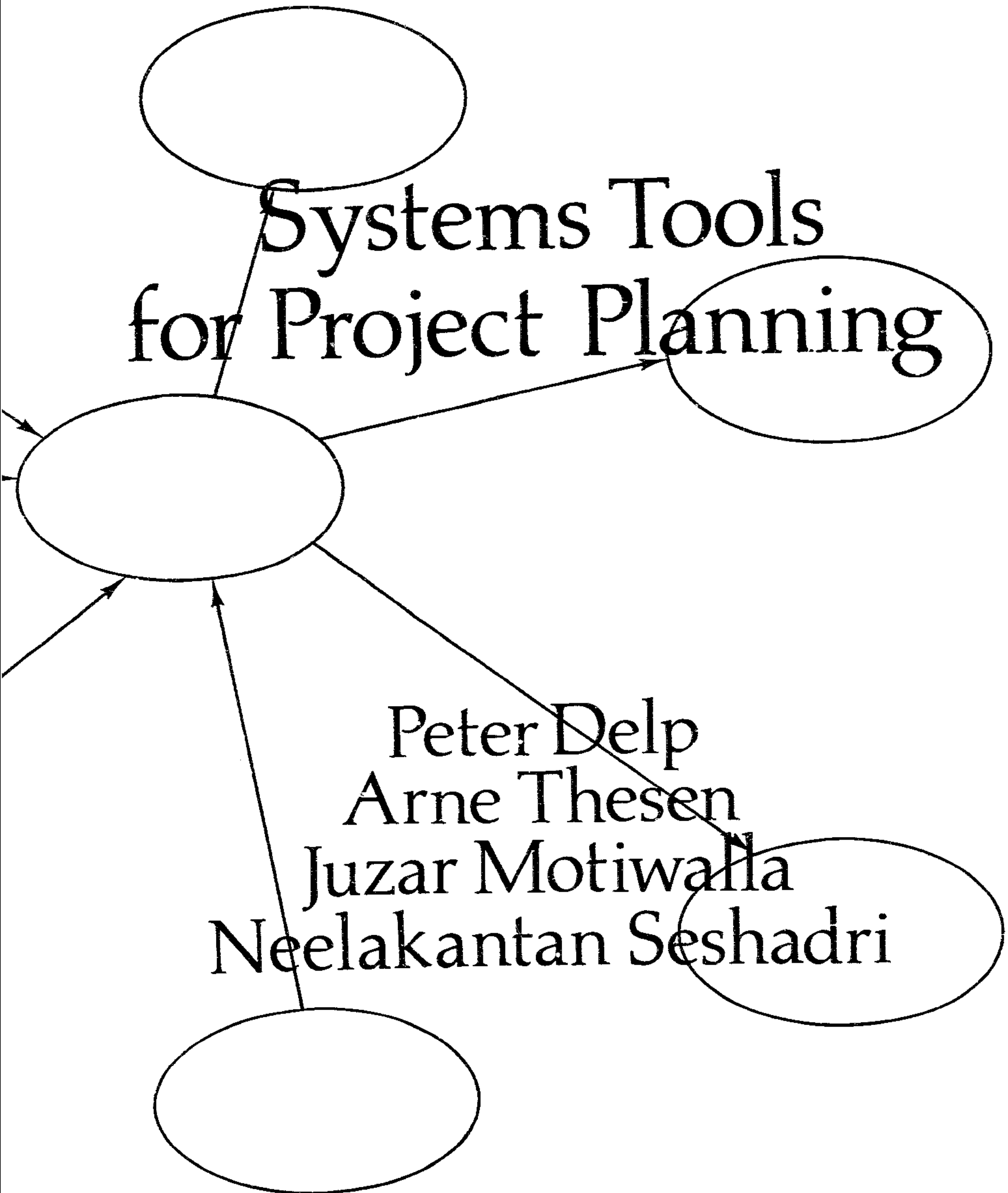

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PASITAM PROGRAM OF ADVANCED STUDIES IN INSTITUTION BUILDING AND TECHNICAL ASSISTANCE METHODOLOGY

International Development Institute
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Bloomington, Indiana

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Contents

VII FORECAST AND PREDICTION

VIII ANALYZING PROJECTS

IX PLANNING, CONTROLLING, AND EVALUATING PROJECTS

List of Figures

Foreword

This is a *toolbook.*

It can be used either as a text or a reference by people studying or doing such things as project analysis.

In principle, analysis is the mother of rationality. The word *analysis* labels a large array of orderly efforts to transform the imponderable into the manageable. People try through analysis to identify the key properties of problematical situations, to contrive promising solutions, and to frame these solutions in convincing ways.

Three things affect the success of such efforts—*the nature of the "reality" being examined, the power of the analysis tools that are used, and the decisional arrangements to which analysis contributes.* What is out there and our interest in it set the basic requirements of analysis. The tools and their use determine what we see and influence what we then try to do. This volume focuses upon tools and their uses. It indicates how they can be applied to study various kinds of realities, or to imposing a sense of order upon real-world concerns. It does not address the third factor which affects the success of analysis efforts—the decision-making settings in which the tools are applied.

The trend of our times is to demand more and better analysis tools in order to try to solve increasingly complicated problems through planned, managed action. The solutions often breed new problems. The expanding pressure to diagnose and resolve outruns our ability to respond. One American sociologist speculates that the ultimate outcome of this dynamic imbalance might be the collapse of societies in "the stupidity death," as the needs to interpret and manage fatally exceed the capacity to do so.

No single book will solve that problem. This one may make some incremental contributions to the intelligent use of analysis in sensible problem-definition and informed solution-seeking. For example, it presents a wide range of analytical tools—about forty—and it classifies them into nine functional categories, from methods of generating ideas to techniques for controlling and evaluating results. There is an important implication here: *there are many kinds of analysis which can be used for a variety of purposes.*

Why does this matter? Partly because the formal analysis strategies of social and economic change organizations are usually quite selective. They are usually skewed in favor of certain kinds of issues and techniques. The pattern of this book at least shows that there are significant categories of analysis beyond the economic and financial, and beyond determinate systems techniques for planning implementation. This is important because some of the best-established, most conventional techniques of analysis, used undiscerningly, make it possible to design unworkable programs and projects.

This book reflects another important idea: *analysis* is not solely the province of insulated experts with little responsibility for entrepreneurship or implementation. Some of the techniques presented here are as useful to "operators" as to "analysts." All of them can profitably be understood by people primarily concerned with promoting and executing projects.

In practice, the interplay of analysis and action is quite complicated. How it works depends chiefly upon the third factor mentioned at the beginning of this brief essay: the decisional arrangements to which analysis contributes.

In most organizations which rely upon analysis as an important input into decisions about programs and projects, systematic analysis and decisional action tend to be rather loosely linked.

A good part of this looseness is necessary and desirable. Studying things and doing things are frequently very different kinds of activity engaged in by different kinds of people. Even so, decision makers and people with discretionary responsibility for executing decisions had better understand the nature—and the limitations—of the analytic techniques upon which their decisions and their mandates may be based; just as analysis specialists will be wise to perceive the practical usefulness of their products and the limits thereof.

Various kinds of analyses produce knowledge for use in designing, reviewing, deciding, and executing programs and projects. Such analysis, coupled with criteria about goals and standards, helps produce decisional frameworks and programmatic targets. It also helps produce decisions about particular plans or proposals: Do they fit within the frameworks? Are they likely to achieve acceptable targets? By helping answer these questions, the analysis may reduce the uncertainty of efforts to shape the future and lessen the need to rely upon hope and intuition. Even when uncertainty defies dissipation, the authoritative use of systematic analysis techniques imposes a degree of *order* and focus upon decision making.

Order is a much valued quality in circumstances where uncertainty abounds. It is also a limited, potentially perverse quality. The quest for order sometimes buries real uncertainties beneath exhaustive analyses. These analyses tools apply techniques which look like formulas or recipes for calculating, deciding, and planning. They are often treated as if they are formulas or recipes. But they are not decisional recipes. Analysis techniques only produce *ingredients* for cooking in decision-making pots, and for envisioning the future. With sufficient skill and judgment these ingredients—the products of analysis—can be used in cooking up programs and projects. But they are readily misused too.

The tendency toward misuse is encouraged by the lopsided, unbalanced quality of our aggregation of tools. The more *intrinsically determinate* the tools, the more attractive they are. Economic analyses and financial analyses, and schemes for "mapping" formalized plans of action (which are actually techniques for hopefully idealizing what is intended), are attractive. Quantitative analyses of costs and benefits, of cash flows, of sensitivities, and so forth, produce determinate answers, even if important data must often be stipulated. Projected maps of future sequences of events have the appeal of apparent certitude, even if they do not tell us *how* these sequences are going to be caused and controlled, or how plausible they are.

To say these things is not to reject the merit of quantitative analyses and precise-looking maps of future courses of action. Both can be valuable, just as both are dangerous in the hands of those who take the products as "true." Unfortunately, these intrinsically determinate techniques are not matched and balanced by methods for analyzing *how best to organize* the activity, *how to determine managerial resource needs* and ways to meet them, *how to specify the incentives* which will increase the probability of success, and *how to measure the full range of effects.* Our tools for doing these latter things are at best rather messy and imprecise. So decisions tend to turn more upon the findings and projections of the neater techniques; and endless effort goes into refining and applying them.

This general observation is reflected in the contents of this book. It does present heuristic techniques for addressing some of the troublesome problems of design—generating ideas, pinning down objectives, and trying to map complex relationships, for example. But, understandably, much of its bulk presents relatively determinate computational tools. Because these are the tools we have.

A longer essay on the interplay of analysis and action would address other important aspects of the subject, such as the use of analysis to manipulate consent and acceptance and the manipulation of analysis to secure acceptance for for proposals. The function of analysis in the decisional processes of development agencies is not limited to the uncontaminated generation of unassailable objective premises, nor can it ever be so limited.

But the ultimate justification of analysis as a kind of activity is its contribution to better knowledge, better understanding, better decisions—to the reduction of error and the enlargement of human capacities for auspicious action. It is to these aims that this toolbook is dedicated.

The book itself is the eventual product of a question put to two young industrial engineers at the University of Wisconsin a few years ago: "What sorts of tools and techniques do you people use in defining problems and shaping solutions which might be transferrable to the field of economic and social development?" Here are the answers provided by Professors Delp and Thesen and their associates.

These answers are neither exhaustive nor definitive; there is little limit to the full array of tools that might be cited. Many of the individual tools offered here are themselves subjects of more than one book. But this work is a valuable introduction and overview. Each tool is presented in a way which facilitates intelligent judgment about its use. The tool descriptions are buttressed by citations which enable the reader to pursue topics of special interest.

If this book should somehow cause one consequential error to be avoided, in the design or implementation of a single project significantly affecting the lives and well-being of some people, the enterprise which has produced it will stand justified. Given the limits of our ability to analyze certain kinds of cause-effect relations we shall never know.

William J. Siffin
Director
IDI/PASITAM
June 1977

Preface

The word "tool," in its strictest sense, refers to an implement, a means for effecting some purpose. When we started the project which led to this volume, we used techniques, methodologies, and tools synonymously to describe various means for planning. On reflection, perhaps the stricter definition is also inappropriate, for this collection represents a set of implements—*tools for implementing a systems approach to planning.*

Systems, system models, and the systems approach tend to blur together into a conceptual mass whose tangible aspects are represented as tools. We've called them "system tools," not because they are necessarily derived from systems concepts or systems engineering, but because they are tools which facilitate a systems approach to planning. A systems analyst uses techniques which shape plans from a systems perspective. The wholistic, future-oriented, inter-relatedness of systems thinking models the situation facing development planners—situations filled with myriad interdependencies, uncertain futures, an ill-defined present, and a data-deficient past. The alternatives to a systems approach tend to produce fragmented, incrementally effective (if not counter-productive) development efforts.

Action-oriented development activities are implemented as policies, programs, or projects. We have used the project concept to represent both programs and policies in the sense that one or more projects are specific activities in order to implement a program or policy of action. The distinction between a project and a system is not always clear.

Often the system tools describe techniques for planning a project or a system. For example, cost-effectiveness analysis is used to evaluate 1) alternative components of a system, 2) alternative systems, or 3) alternative projects (which may involve many interacting systems). In many cases, techniques for project design and techniques for system design are indistinguishable.

Planning, as we have used the term, encompasses the entire range of activities associated with achieving development ends. Planning a project requires that all aspects of the project be designed or specified. This includes identifying objectives, sub-objectives, and criteria for evaluating the achievement of objectives. It includes specifying the essentials of implementation—those messy details of getting from an idea to a project. A systems approach to planning requires that the requisites of management be incorporated into the design and that the essentials of evaluation be considered *in the planning process.* Short-term feedback systems to provide management information are designed to complement long-term feedback of project impact in order to inform development planners. This broad view of planning and its intimate connection to implementation has guided our selection of techniques and their descriptions.

One aspect of the description which needs elaborating is our distinction between decision makers and analysts. Certain techniques require special skills for successful implementation (e.g., Surveys, Cost-Benefit Analysis). An analyst, possessing these needed skills, may also be the decision maker. In some techniques the two roles are distinct (Delphi, Program Planning Method), while in others the separation of roles is not important. A decision maker has discretionary control over resources including those required for analysis. Therefore, he views the problems of project planning from a different perspective from the analyst and usually a different degree of accountability. This reflects not only the way techniques are employed, but the decision to employ a particular tool. The classic case is an analyst who needs information recommending a sample survey, and the decision maker reconsidering this approach because of political sensitivities. We have included this distinction where relative to the application of the technique.

While we have sought to be comprehensive in our coverage of systems tools for planning, we recognize the omission of a great body of planning techniques developed in such fields as econometrics, business, and operations research. Linear programming, input-output models, or matrix algebra are useful planning tools, but they represent a level of sophistication, a rigidity of models, and a dependency on accurate data and computer implementation which seem inappropriate for the intended audience of this volume.

This collection of techniques and methodologies is intended for practitioners in the many diverse fields in which development touches both the peoples' lives and livelihood. Our examples are drawn from agriculture, education, health, family planning, employment, and resource management to underscore our belief in the universal utility of these tools in planning. We have focussed on project design and implementation as the action interface of planned development.

Peter Delp
Nairobi, 1977

Acknowledgments

Producing a volume of this scope is a long and difficult process. The support, constructive criticism, and encouragement of many have helped us in this endeavor.

We must begin by thanking the many authors who developed the techniques described in this volume. We have tried to give appropriate credit in the last sections of each tool description, citing the originators of the techniques where appropriate.

We are particularly indebted to our colleagues at the University of Wisconsin, Professors Andre Delbecq, Dave Gustafson, Howard Harrison, and Gerald Nadler. Their names will be found throughout the bibliographies for the techniques. We gratefully acknowledge their contributions, while excusing them for all responsibility for any errors or misinterpretations in our renditions.

Valuable criticism and support were provided by Dr. Richard Blue and Dan Creedon, United States Agency for International Development; Richard Hook and John Thomas, Harvard Institute for International Development; William Siffin, Russell Stout, and Paul Cunningham, Indiana University. Dr. Siffin's promotion, support, and professional guidance of this project from conception to final product was highly valued by the authors.

We are indebted to the Program for Advanced Studies in Institution Building and Technical Assistance (PASITAM) for providing the support necessary for redrafting materials used in this volume.

Final editing and production has been the responsibility of Marianne Platt who deserves major credit for transforming the writing of system engineers into useful communication. Ms. Platt worked closely with Peter Delp over the course of a year, editing and revising the work of four authors into a coherent volume. Other members of the PASITAM production staff deserve much credit for professional work, especially Clancey Maloney who inked the many diagrams appearing in the volume.

We need also to thank Pat Hochmuth who edited the first working draft, and Suzanne Machett and Doreen Marquardt who cheerfully endured our endless demands in order to produce a first draft.

A final tribute is due our families and friends, especially Sandra Kalscheur, without whose support, encouragement, and (often) direct assistance, completion of this work would not have been possible.

The Authors

Abbreviations

BCR	Benefit-Cost Ratio
BSG	Brainstorming
CBA	Cost-Benefit Analysis
CEA	Cost-Effectiveness Analysis
CFA	Cash Flow Analysis
CGA	Contingency Analysis
CPM	Critical Path Method
CSM	Computer Simulation Models
DIS	Discounting
DLP	Delphi
DTB	Decision Tables
DTR	Decision Trees
EXF	Exponential Smoothing Forecasts
FEX	Function Expansion
FLW	Flowcharts
GAM	Gaming
GNT	Gantt Charts
HIS	Histograms
IDL	IDEALS Strategy
IMD	Interaction Matrix Diagramming
INS	Intent Structures
IPX	Impact-Incidence Matrix
IRR	Internal Rate of Return
IVW	Interviews
LGF	Logical Framework
MCU	Multiple Criteria Utility Assessment
MPA	Morphological Analysis
NGT	Nominal Group Technique
NPW	Net Present Worth
OBT	Objective Trees
OCA	Organizational Climate Analysis
OVD	Oval Diagramming
PPB	Planning, Programming, and Budgeting
PPM	Program Planning Method
QTN	Questionnaires
RGF	Regression Forecasting
RTS	Rating Scales
SCN	Scenarios
SDM	System Definition Matrix
SPA	Subjective Probability Assessment
SVY	Surveys
SYN	Synectics
TRD	Tree Diagrams

Introduction

Designing development projects requires some form of "systems" approach. If any plan is to succeed, the factors that will probably determine the outcome must be identified, and their relationships must be established. There will always be surprises as implementation proceeds, for our ability to predict and control the future is limited. The object of planning and design is to keep those surprises at a minimum. A systems approach, properly used, can serve this aim.

There is another justification for a systematic approach to project planning and design: Even the simplest interventions have secondary effects—consequences which are easily overlooked because they are incidental or even irrelevant to the project itself. An irrigation project, designed to raise farmer income through increased productivity, may threaten established social and economic relationships. It may introduce water-borne disease vectors. It may have other unintended consequences which, in some cases, are more important than the direct impact of the project.

In the West, the word "systems" has acquired, for some people, a certain magical quality. The term is used promiscuously, vaguely, and enthusiastically. The problem lies not in the meaning of that term, but in the way in which it is applied.

Conceptually, a *system* is simply a set of interactive elements. In conventional usage, the term refers to a set of factors which are known (or assumed) to be necessary and sufficient to some purpose or effect. Systems thinkers often work backward, beginning with a desired objective and then determining what factors are needed to accomplish that objective and how those factors must be related. The success of this approach to design depends not on the use of the term "system," but on the ability of the designers to truly know what is necessary to the desired effect.

There are many areas where such knowledge exists, for example, in designing an electric motor, an automobile, an airplane, a computerized data processing program, or a water control system. In these and similar examples, the system can be thought of, for all practical purposes, as "closed." It is a tidy system. There is relatively perfect knowledge of its parts, and of their relation to a desired effect. And the essential relationships between the system and its environment can be known and controlled.

Problems arise when this alluring idea of "system" is transferred from the fields of determinate design into the messy world of "open systems." These are loose and not necessarily stable arrangements in which the environment of an action system, such as a government program, an enterprise, or a farming venture, is always affecting the working of that system.

In the language of systems, the "environment" consists of the factors which affect the system's working but which are not subject to full control from within the system. The weather is an important environmental factor in agricultural systems. "Politics" constantly affects the behavior and potential of a bureaucratic program system. In short, open systems are not nearly so determinate or so capable of precise specification as the more closed systems of insulated engineering. There are two potential dangers in applying the idea of a system to designing development projects.

The first is the danger of failing to identify essential elements of an open system, or to effectively judge their probable working. A systems perspective cannot guarantee against this danger. It cannot tell you ahead of time what the factors are or how they will work. It can, however, make you aware that they exist and that you had better try to find and assess them.

The second danger might be labeled "undue narrowness," the danger that "incidental" effects may be ignored or undervalued. This can result from systems analyses which, as noted above, start with some desired aim or goal and then work backward to identify the necessary and sufficient factors for meeting the goal without also considering the *other* effects which those factors will have.

It is possible to examine and analyze the larger array of effects produced by any system. Some systems approaches fail to address this vital matter, but *only* a broad systems perspective can consider these effects in a reasonably orderly way. Therefore, the systems approaches reflected in this collection of tools and techniques are *comprehensive*. The aim is to help people search systematically for the broad implications of planned change. The approaches supported by these techniques are *future-oriented*. They offer help in trying to forecast immediate and longer-term effects in open systems designs. The approaches supported by the following tools are essentially *pragmatic*. They address the realities of the socio-political environment of any of the kinds of systems likely to concern us.

In these approaches, the systems analyst attempts to deal with unbounded complexity by identifying a set of salient variables which describe the problem. The organizing concept is the notion of a system, defined not as a static but as a dynamic entity. The values of descriptive variables and the status of relationships are projected into the future in order to look at the consequences of planned interventions. The systems designer recognizes both the limitations of deterministic analysis and the realities of power as it invariably affects the best laid plans. Consequently, a hallmark of a systems approach is pre-planned adaptability. Adaptive systems are better equipped to deal with uncertain futures, the vagaries of power, and the realities of complex political, social, and technical interactions.

Engineers have long straddled both hard and soft approaches to problems. In true engineering fashion, he/she uses whatever technique fits the task or promises insights into solutions. For the non-technical aspects of problems, the systems engineer must turn to other disciplines.

APPLYING A SYSTEMS APPROACH

Tackling complex problems requires a variety of techniques. Flowcharts (FLW, page 107), a diagramming technique which flourishes in the computer sciences, show the logic and sequence of complex computer programs. Not much imagination is required to adapt the technique to the complex decision processes confronting development planners. The aim for design remains the same: using the technique to understand the determinants of decision and action.

This adaptation of systems technology (software) to the complex realm of human behavior is a two-way street. Behavioral scientists have developed systems oriented techniques which have been readily adopted by project designers. Brainstorming (BSG, page 3) and Nominal Group Technique (NGT, page 14) emerged from a marriage of small group theory and empirical creative process analysis. System designers utilize the techniques because of their demonstrated power in generating ideas and innovative solutions.

Criteria used for selecting (or excluding) techniques from the volume were based on the needs of the intended audience. Many sophisticated techniques utilizing optimization theory and computer technology fill the systems literature and seem inappropriate for meeting the needs of a project planner in the field. Consequently, linear programming techniques, queuing and game theory, input-output models, and cross-impact matrices have not been included. By and large nothing more sophisticated than a pocket calculator is required for any of the tools. The exception is Computer Simulation Models (CSM, page 120), which was judged sufficiently important that a summary description was included. Complex mathematical formulations have been avoided, except where a step-by-step procedure can be described (see Regression Forecasting, RGF, page 160, and Discounting, DIS, page 184).

TOOL DESCRIPTIONS

Each tool describes what the project planner needs to know in order to 1) select a tool, 2) utilize the tool, and 3) understand its implications and underlying theory.

To aid selection, each tool begins with a brief statement of purpose and a summary of uses. A short description follows (supplemented by key definitions) and is augmented by a listing of advantages and limitations. The decision maker is thus given a brief overview of the tool to help him decide if the technique is a candidate for addressing a problem. To this end, a section on required resources (effort, skills, time) concludes the first part of each tool description.

In order to use a tool, a detailed description is needed, beginning with required inputs, expected outputs, and important assumptions. Moving from inputs to outputs involves a procedure, which is described for the tools at differing levels of detail. An example illustrates the procedure.

Finally, a brief section on the underlying theory and a bibliography conclude the tool description. Together with the listing of assumptions and limitations, these attempt to give each tool a theoretical base, while leading the reader to additional sources.

Ideally, each tool description should be self-sufficient, but in order to save space and provide essential continuity, the prerequisites of each tool precede the description. For example, the description of cost-benefit analysis (CBA, page 212) takes the form of a summary linking prerequisite tool descriptions comprehensively. In some cases, a common example is carried through several tools.

The examples draw on a broad range of problems and situations confronting project planners in the development fields, ranging from education and health to agriculture and economic policy. Most of the examples refer to the developing country of Temasek which (for convenience) has a widely varying climate and diverse ecological zones. The population is mostly agrarian. The examples are drawn from first-hand experiences, hypothetical situations, or the literature.

USING THE SYSTEM TOOLS HANDBOOK

The tools included in this volume fall into a number of categories: generating ideas; assessing qualitative factors; defining objectives; describing complex relationships; analyzing complex processes; accounting for alternative outcomes; forecast and prediction; analyzing projects; and planning, controlling, and evaluating projects. Clearly, many techniques could be included in more than one category. For example, computer simulation models (CSM, page 120) could be used for the last six purposes listed. It is presented in analyzing complex processes because that is the most basic use of computer simulation.

Each tool is designed to stand alone as a source of information for a decision maker, as an aid to the analyst, and as a catalyst for multidisciplinary design teams. The tool description (together with any prerequisite tools) provides a basis for action and/or the evaluation of actions by others (e.g., permitting a decision maker to interpret the models used by analysts).

DEVELOPING SYSTEM MODELS

Three tools are paramount to the description of any system: Tree Diagrams (TRD, page 74), Oval Diagramming (OVD, page 81), and Interaction Matrix Diagramming (IMD, page 92). Each describes the complex relationships of a system and defines a system as distinct from its environment.

One possible sequence for using the tools is given in figure 1a. The analyst uses a tree diagram (more specifically, an influence tree) to develop the relationships which prescribe system behavior. This leads to a specification of system variables and environmental factors which influence variables within the system. At some point, the tree diagram is redrawn as an oval diagram to show the feedback relationships and multiple interactions of system variables. If the oval diagram becomes too unwieldy, the analyst may turn to a matrix description. This has the distinct advantage of systematically pinpointing every possible interaction among system and environmental variables, while refining the oval diagram.

The analyst may wish to begin with an interaction matrix diagram rather than a tree diagram (see figure 1b). This approach appeals to those who are more comfortable separating the identification of variables from the specification of relationships. A tree diagram or an oval diagram is then used to interpret the interaction matrix in a form which permits tracing the sequence of cause and effect. An interaction matrix diagram is particularly useful in breaking down information-gathering and analysis tasks into distinct groups, thus facilitating task assignments.

The oval diagram constitutes a first attempt at a causal model of the system: it presents an explicit statement about key variables as well as hypotheses about cause and

FIGURE 1a

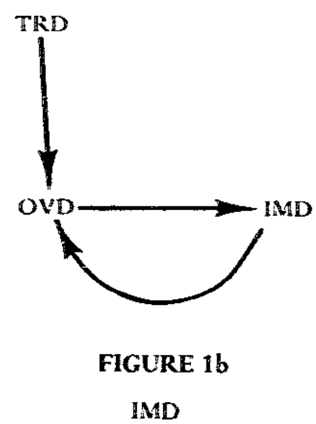
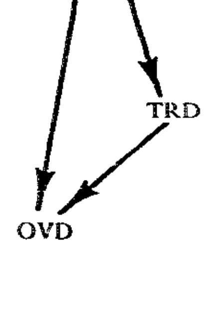
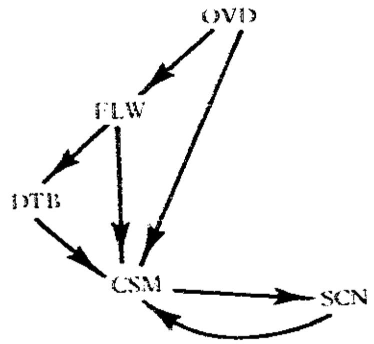


FIGURE 1b



effect relationships. These hypotheses may be tested by regression analysis (see RGF, page 160) and then quantitatively modeled. The oval diagram is then used in various ways to gain greater understanding of system behavior (see figure 2). For example, a computer simulation model (CSM, page 120) can be constructed in order to predict the consequence of changes in the system. A scenario (SCN, page 164) may be developed using the oval diagram as a basis for describing the base state and the kinds of changes expected in the future.

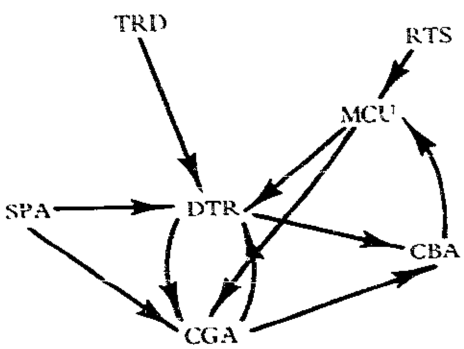
FIGURE 2



GENERATING AND ANALYZING ALTERNATIVE PLANS OF ACTION

Tree diagrams in the form of ends-means diagrams (see TRD, page 74) are useful for breaking a system into components or an objective into alternative means. This begins a sequence using several techniques to analyze alternative plans (see figure 3). The central tool in this process is the Decision Tree (DTR, page 141). Branches of a decision tree map alternative actions and probabilistic outcomes. The alternatives may be identified by the tree diagram branching process or the matrix format of morphological analysis (MPA, page 10). The probabilities of various outcomes are often subjectively assessed (SPA, page 137). Closely related to the decision tree, contingency analysis

FIGURE 3



(CGA, page 147) tabulates alternative plans against the various possible states of nature which affect the outcomes.

Outcomes for both techniques are expressed either as monetary units (costs and benefits) or as utilities, using a concept which translates preferences for an outcome into a dimension on an interval scale (see RTS, page 29). Utilities assessed for various criteria are combined in Multiple Criteria Utility Assessment (MCU, page 32).

In short, these possible sequences of tools (figure 3) describe a process of analysis which begins with generating alternatives and results in an evaluation of alternative outcomes. The end use may be employed for a cost-benefit analysis or for the selection of plan elements.

CO-OPTING CLIENTS, RESOURCE CONTROLLERS, AND EXPERTS INTO THE PLANNING PROCESS

There is a set of techniques which claim their greatest strength in their ability to generate cooperation among various actors on the planning stage. The central tool is the Program Planning Method (PPM, page 227). Supporting this tool are a number of techniques, each of which is powerful when used alone and potentially more so when incorporated into a strategy (see figure 4). The Nominal Group Technique (NGT, page 14) permits maximum efficiency in generating ideas. It is particularly effective when used by diversely composed groups.

A companion technique is the Delphi process (DLP, page 168) to which experts and decision makers contribute without face-to-face confrontation. This anonymity is often necessary if the pursuit of ideas and constructive problem exploration is not to be hindered by social and bureaucratic sanctions. The Delphi utilizes repeated rounds of questionnaires (QTN, page 19).

The Program Planning Method combines these techniques to produce plans which co-opt clients, resource controllers, and experts in a carefully orchestrated planning process.

A NORMATIVE APPROACH TO PLANNING

One planning strategy begins with a normative concept of the ideal system, rather than analyzing what could be

FIGURE 4

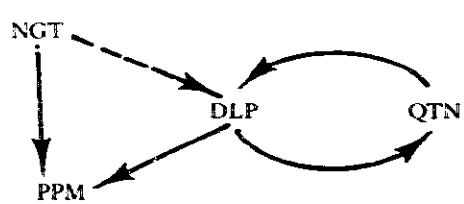
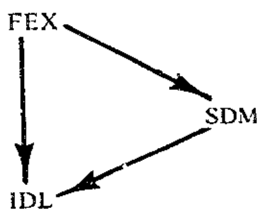


FIGURE 5



wrong with the existing one. This strategy is embodied in the IDEALS Strategy (IDL, page 231). Two other techniques support this approach (see figure 5).

Function expansion (FEX, page 45) forces the system designer to think in terms of the purpose of the system desired—what the system should be doing. This leads to a specification of the "ideal system target" which becomes the basis for designing a feasible system, using essentially the system design strategy. The form of the specification is the system definition matrix (SDM, page 67), which is the output of the IDEALS process.

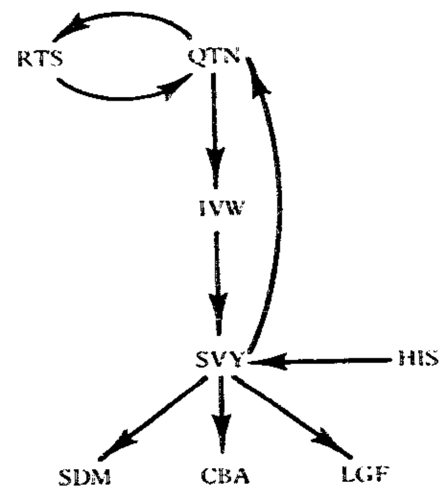
Focusing on function rather than on problems gets people involved in a constructive assessment of what should be, rather than what's wrong and who's to blame. There are sound arguments for both approaches. The IDEALS Strategy often comes under attack because its emphasis on normative specification may possibly ignore experiences gained from problems with the existing system. If the ideal system target proposes a radical change, where only incremental changes are acceptable, normative prescriptions may be counterproductive. Still, there is an intuitive appeal to any process that encourages minds to explore an unlimited problem-solution space, unbounded by existing system descriptions.

USING SAMPLE SURVEYS TO GATHER INFORMATION

A sequence of techniques is particularly useful for gathering information across a broad spectrum. The principal technique is the sample survey (SVY, page 36), which begins the design of the survey questionnaire (see figure 6). Where subjective assessments are to be quantified and aggregated, the questionnaire may incorporate rating scales (see RTS, page 29).

The questionnaire (QTN, page 19) must be pretested and refined so that the objectives of the survey may be realized. The means for obtaining the desired information may vary greatly, but one useful technique is the direct interview (see IVW, page 23). This is usually the preferred approach in pretesting the survey because it requires less time and gives more design information than mailed questionnaires. The latter technique, however, is widely used

FIGURE 6



when a large sample is to be covered by the survey, even though a high return is seldom possible.

The survey results are quantified and aggregated, often in the form of histograms from which statistics may be computed (HIS, page 131). These results are then used to formulate policies, to specify system design (see System Definition Matrix, SDM, page 67), to quantify costs and benefits (CBA, page 212), and to evaluate programs (see Logical Framework, LGF, page 260).

PROJECT FINANCIAL ANALYSIS

The financial analysis of projects is a sequential process which begins by identifying costs and benefit time streams (Cash Flow Analysis, CFA, page 177) and culminates in the presentation of recommendations (and assumptions) to decision makers (see figure 7). Many techniques support this analysis at each stage. A survey may be necessary to gather financial and production data. The various impacts of a project may be tabulated across directly and indirectly affected groups in an impact-incidence matrix (IPX, page 207). This technique attempts not only to quantify all impacts of a project, but nonmonetary impacts of a project using rating scales (RTS, page 29).

The time streams of costs and benefits are discounted to give their present value in order to compare project alternatives (see Discounting, DIS, page 184). The criterion for comparison may be net present worth (NPW, page 188), benefit-cost ratio (BCR, page 194), internal rate of return (IRR, page 200), or a combination of these.

The cash flow analysis, the evaluation criteria, and the impact-incidence analysis are brought together in cost-benefit analysis (CBA, page 212). The end result may take the form of a single go-no go decision on any one project, or a ranking of alternative projects for funding.

FIGURE 7

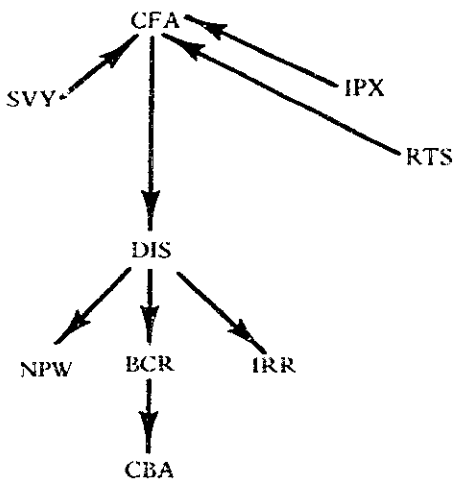


FIGURE 8

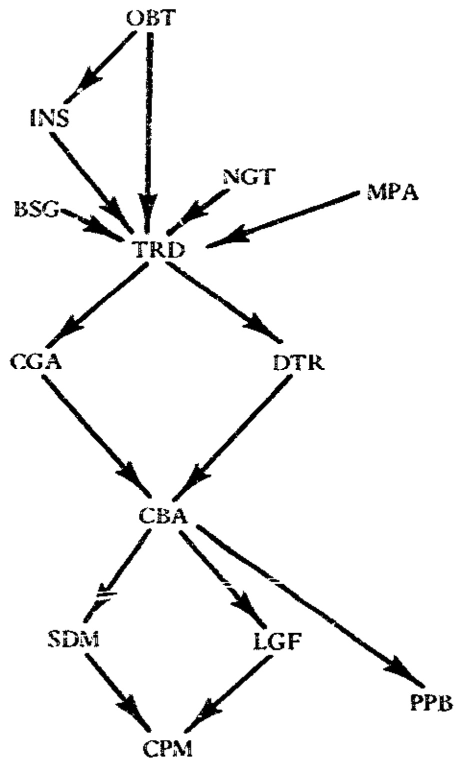
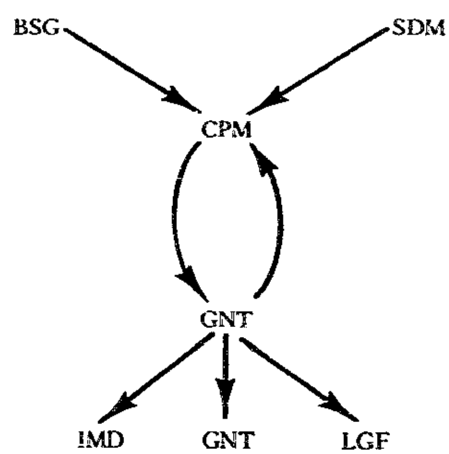


FIGURE 9



THE "CONVENTIONAL" SYSTEMS APPROACH

Systems analysis begins with identifying objectives, specifying alternative means, specifying the criteria for selecting among the alternatives, and then synthesizing a system or plan from the choices. A sequence of techniques for applying the systems analysis strategy begins with Objective Trees (OBT, page 49) and/or Intent Structures (INS, page 55) (see figure 8). Brainstorming, Nominal Group Technique, or morphological analysis may be used to specify alternative means (see also Tree Diagrams, TRD, page 74). The alternatives are analyzed using either decision trees or contingency analysis to develop the project plan. Cost-effective analysis, multiple criteria utility assessment, or both are used as criteria for evaluating alternatives. The plan may be specified as a System Definition Matrix, Logical Framework, or as an operating Planning, Programming, and Budgeting system (PPB, page 236). This strategy is not altogether different from the IDEALS approach; however, the starting point of the latter is the function of the system rather than objectives for a project.

PLANNING PROJECT ACTIVITIES FOR IMPLEMENTATION AND CONTROL

Two complementary techniques which specifically address the scheduling of project activities are the Critical Path Method (CPM, page 241) and Gantt Charts (GNT, page 252). The techniques may be incorporated into a strategy which plans and facilitates the implementation of a project.

Critical path techniques begin with a list of project activities essential to the achievement of project goals (see figure 9). The list may be generated using techniques such as brainstorming or, more formally, from a system specification (see System Definition Matrix). From the critical path network, a Gantt (bar) Chart may be prepared, enabling a planner or manager to schedule activities and resources. He may wish to present the activities and officers responsible in an interaction matrix (IMD, page 92) in order to emphasize both the interrelatedness of tasks and the multiple staff responsibilities. A Logical

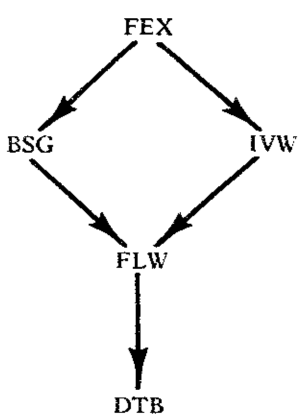
Framework may also be used to sharpen the identification of objectively identifiable indicators of progress. These milestones are shown as vertical lines on specific dates of the Gantt Chart and written on the Critical Path Method network at the appropriate nodes.

Altogether, the techniques serve to ease the manager's job by breaking down a complex project into finite tasks with planned start and end dates. Progress monitoring permits effective use of staff which is essential to successful project implementation.

ANALYSIS AND PROGRAMMING OF DECISION PROCESSES

A decision-making system exists for a specific purpose. The first step in any analysis is a function expansion to specify that purpose (FEX, page 45) (see figure 10). The aim is to specify the key decision points and the conditions which lead to particular actions, i.e., the decision-making policies. Two processes may be used to obtain this information. If the system exists, decision makers may be interviewed (IVW, page 23). If the task is to design a system, then idea generating techniques (e.g., Brainstorming, BSG, page 3) are used.

FIGURE 10

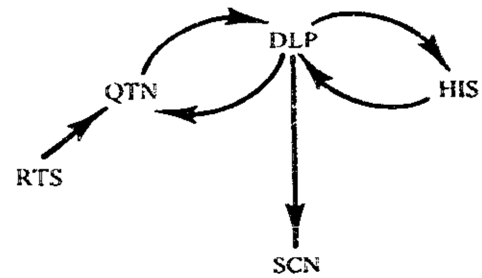


The results of this analysis are presented in the form of flowcharts (FLW, page 107) or decision tables (DTB, page 113). The flowchart uses different symbols to display and analyze complex processes. The decision table presents the decision as a preprogrammed process by specifying the conditions which precede—and the action which follows—a decision. Both techniques are usefully employed in management training as well as in diagnosis of potential problems in implementation.

QUALITATIVE FORECASTING

A scenario draws on a variety of expertise to produce a map of the future states of a system (SCN, page 164). It is the result of a strategy which incorporates intuition and judgments into a coherent framework (see figure 11).

FIGURE 11

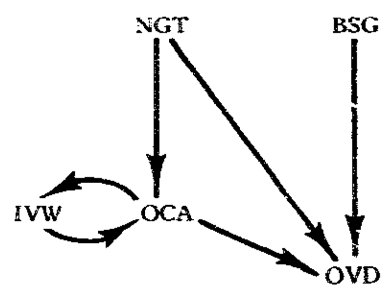


The Delphi technique (DLP, page 168) begins by directing questionnaires to a selected group of prognosticators. The results of each round are summarized for the Delphi group, often in the form of a histogram which aggregates the individual judgments. Rating scales attempt to quantify priorities and opinions. The Delphi rounds are then used to produce the successive state descriptions of the scenario. The desired result is a clearer understanding of the forces and constraints which are involved in planned change.

PROBLEM ANALYSIS STRATEGIES

Problems in systems (whether ongoing organizations or newly designed projects) may be analyzed by using a number of techniques, none of which guarantees a solution. Rather, they promise a greater understanding of the dimensions of the problem. Two techniques are central to the analysis of problematic behavior: Oval Diagramming (OVD, page 81) and Organizational Climate Analysis (OCA, page 40) (see figure 12).

FIGURE 12



Problems are first identified using a technique such as Intent Structures (INS, page 55) to specify conflicting objectives and competing interest groups. The Nominal Group Technique (NGT, page 14) or brainstorming (BSG, page 3) may also be used. The problems lists may be employed to guide the information-gathering, the interviewing necessary for an analysis of organizational climate, or the tackling of identified problems by a Synectic problem-solving team (SYN, page 6). The very least to be expected from a Synectics group is a better definition of the problem and a creative attempt at a solution.

One highly recommended technique for combining all these analyses is an oval diagram which describes the system or organization. Most problematic behavior stems from poorly designed feedback of information within a system, and poor understanding of the far-reaching effects of actions.

The analyst may ultimately wish to test the problem analysis by using management games (see Gaming, GAM, page 124) which are carefully designed to identify problems which arise from simulated interaction among system and organizational components.

CONCLUSIONS

This volume is a collection of techniques drawn from a variety of disciplines and presented in a standard format in order to bring together various means to a common end—better development project design. The organizing theme is a systems approach to project planning. The techniques are means to developing project designs which are comprehensive, future-oriented, and pragmatically shaped by the realities of power and uncertainty. While no single technique is the systems engineer's unique contribution, all should contribute to better project design.

I
Generating Ideas

Brainstorming
Synectics
Morphological Analysis
Nominal Group Technique
Questionnaires
Interviews

Techniques for generating ideas and gathering information are essential for project planning. Eliciting information from clients, experts, and decision makers in order to generate innovative alternatives is a crucial step in a systems approach. The selected techniques structure group "creativity" (Brainstorming, Nominal Group Technique, and Synectics), promote systematic synthesis of alternatives (Morphological Analysis) and formalize interpersonal communication (Interviews and Questionnaires). Two of the techniques gain their strength through interacting group processes (Brainstorming and Synectics) in contrast to carefully structured group interaction (Nominal Group Technique).

Brainstorming

PREREQUISITE TOOLS

None.

USAGE

PURPOSE

Brainstorming is a group creative process used to generate alternative ideas and suggestions in response to a stated question or problem.

USES

Brainstorming is used to:

1) Generate many alternative solutions to a problem.
2) Generate alternative ways of looking at a problem.
3) Identify experts who will aid in different problem-solving phases.

SHORT DESCRIPTION

Brainstorming is a group process where the members, usually from different backgrounds, respond to a central question or theme. Emphasis is placed on generating a large number of ideas while deferring criticism and evaluation. Brainstorming is especially useful for attacking new problems or for identifying new ways of looking at old problems.

ADVANTAGES

1) Original and innovative ideas may be generated if premature criticism is not allowed to inhibit spontaneity.

2) Cross-fertilization of ideas occurs, especially when the group is composed of experts from different fields.

3) The relatively unstructured nature of brainstorming is sometimes preferred over methods like the Nominal Group Technique (NGT, page 14).

LIMITATIONS

1) Brainstorming may be unproductive if the group members are meeting each other for the first time during the session. The effectiveness of a brainstorming session is greatly enhanced when the members know each other before the session and when they are motivated to solve the problem under consideration (Bouchard, 1971).

2) Superior-subordinate relationships outside the session may affect the free interchange of ideas within the session.

3) A brainstorming session often involves misdirected discussion which may be unproductive and a waste of time.

4) Discussion may be dominated by one or two members, and may stifle the participation of other members. This is in contrast with Nominal Group Technique (NGT, page 14).

REQUIRED RESOURCES

LEVEL OF EFFORT

For brainstorming sessions to be effective, all participants should contribute to the discussion in order to facilitate the cross-fertilization of ideas. It may require some effort by group members to defer their natural tendency to criticize or otherwise evaluate the ideas presented.

SKILL LEVEL

No special skills are required. Some practice may be necessary before brainstorming sessions are productive. Generally, members will bring expert skills, but they must be able to extrapolate beyond their own experience. The group leader will be more effective if he has some training or experience in conducting brainstorming sessions, particularly in order to recognize when the group becomes misdirected.

TIME REQUIRED

Brainstorming sessions which last longer than an hour are usually unproductive. The time span is proportional to the number of participants. It also depends on the novelty of the question under consideration.

SPECIAL REQUIREMENTS

Blackboard and chalk, or a flip chart and marking pens, are used to record all suggested ideas. Writing materials for each member are needed. A tape recorder may be used to record the session.

DESCRIPTION OF TOOL

REQUIRED INPUTS

1) A statement of the problem, usually in the form of a question, focuses participants' ideas, e.g., "How can the increase in Temasek's population be stopped?"

2) Participants may be experts, consumers, clients, or practitioners. Contributions, however, may be made by experts or creative people from unrelated fields.

TOOL OUTPUT

The principal result of a brainstorming session is a large number of ideas which may serve as possible answers to the question. For example, brainstormed answers to the problem of slowing population increase may be:

Educate on family planning
Make contraceptives free
Shoot people regularly
Sterilize men or women
House men and women separately

These answers are not qualified or evaluated. The evaluation is done by using techniques like Decision Trees (DTR, page 141) or Cost-Benefit Analysis (CBA, page 212). Seemingly outlandish ideas are not immediately rejected; they may generate more practical alternatives.

IMPORTANT ASSUMPTIONS

1) The brainstorming technique assumes that the group process of generating ideas will be more effective than independent efforts (if not in total number of ideas, then in quality of ideas generated).

2) It is assumed that participants will overcome their inhibitions and discuss ideas freely.

METHOD OF USE

GENERAL PROCEDURE

The procedure is addressed to the person who will conduct the brainstorming session.

1. **Organize the group.**
   - 1.1 Identify potential participants, keeping in mind the nature of the problem. For example, if the problem concerns population control, potential participants are a physician, a psychologist, a government official, a health care administrator, community workers, potential clients, etc. The organizers of a brainstorming session may use the technique to generate the list of potential participants for future problem-solving groups.
   - 1.2 Limit the group size to seven to ten. Sometimes larger groups are used, though they tend to decrease the usefulness of the sessions.

2. **Instruct the participants.**
   - 2.1 Explain the four guiding principles of brainstorming:
     - a) There are no correct or incorrect ideas. All ideas are accepted on equal ground.
     - b) Novel and creative ideas are encouraged regardless of how foolish they may seem. Criticism is not allowed.
     - c) Emphasis is on generating a large number of ideas in order to get "all around" the problem.

d) Combinations and extensions of ideas are encouraged.

2.2 State the question or problem under consideration and discuss it briefly in order to clear up misunderstandings. Let the participants think about the problem for a few minutes. Indicate that they can make notes, but discourage any outbursts like, "I've got the solution!"

3. Conduct the session.

3.1 Ask a participant to respond to the question and to briefly explain it. Participants may take turns, giving one idea at a time, or the process may be spontaneous. In both cases, an idea suggested by one member often triggers an idea from another. This is referred to as "leap-frogging." Encourage "leap-frogging" in the group, since one aim is the generation of a large number of ideas. However, the leader should exercise his judgment in keeping order in the session.

3.2 If necessary, remind members about the rules of brainstorming during the session. Sometimes members need a new direction, or they may be tactfully asked to curtail extraneous discussion. An atmosphere of cordiality and free expression must be maintained at all times. The session leader must exercise careful judgment.

3.3 Sometimes it is useful to present a mock problem to the group to familiarize members with the method. An exercise where members generate all possible uses of a machine or technique is helpful. A problem example might be "list conventional and unconventional uses for a bicycle." Such an exercise might relax the members and make the main session more effective.

3.4 Have all ideas recorded as they are generated. A tape recorder may be used to provide a record, but this method doesn't allow for immediate reference to previous responses. When no more ideas are generated, end the session.

EXAMPLE

Consider a situation where the help and authority of a local government official is needed to implement a health care project. The problem is how to obtain the cooperation of this person in a reasonably short time. Commandeering bureaucratic support from his higher authorities can often be a lengthy and uncertain process.

A brainstorming session is organized. Participants include the project leader, a local person affiliated with the project, a troubleshooter in an election campaign, etc. Some brainstormed suggestions are given below.

1) Appeal to the local official, emphasizing the importance of the project.

2) Bribe the local official.

3) Bribe the higher authority (triggered from idea 2).

4) Disregard authority and do without local help.

5) Move to another area where the local official is more cooperative.

6) Use the media to apply political pressure on the authorities.

7) Convince the local elite of the importance of the project and work through peer pressure.

THEORY

One principle in the theory of creativity is that evaluating or ranking an idea stifles the generation of further ideas. Therefore, generation should be separated from evaluation. Another principle states that group processes may be more effective than individual efforts in generating ideas, largely because of cross-fertilization. See Bouchard (1971) and Osborn (1963) for a more detailed discussion of the theoretical bases of brainstorming.

BIBLIOGRAPHY

Bouchard, T. J. "Whatever Happened to Brainstorming?" *Journal of Creative Behavior* 5 (1971): 182-89.

Osborn, A. F. *Applied Imaginations and Creativity*. New York: Charles Scribner and Sons, 1963.

Synectics

PREREQUISITE TOOLS

None.

USAGE

PURPOSE

Synectics is an interacting group process for generating creative ideas in response to a problem.

USES

Synectics is used to:

1) Identify possible solutions to a given problem.

2) Infuse novel thinking into one technology or discipline by transferring knowledge and expertise from another technology.

SHORT DESCRIPTION

A group effort is directed to problem definition and creative problem solving. The group discussion relies on two basic concepts: "making the strange familiar" and "making the familar strange" (Gordon, 1961).

Synectics depends, first of all, on finding analogies to a strange or novel situation (in the problem context) in order to make it familiar (making the strange familiar). In contrast, "making the familiar strange" means to enhance the possibility of new solutions by looking at something familiar from a different viewpoint.

Different kinds of analogy are used during a Synectics session to draw out these ideas, e.g., comparing parallel situations in different fields. The group's ideas may then be explored and developed into possible solutions, often by a technical staff member who sits in on the session.

ADVANTAGES

1) Solutions generated by the Synectics method may be quite novel and innovative. The technique draws out the creative expression of participants.

2) Different analogies used in Synectics provide creative insights into the problem.

3) After participating in repeated Synectics sessions, a trained team is available for attacking new problems.

4) Regular participation in Synectics sessions may improve a member's creative thinking outside of the sessions.

LIMITATIONS

1) Synectics requires that the members communicate freely and often impersonate inanimate objects or abstract ideas. Some people may be inhibited and may not participate activeiy in the group sessions. Also, superior-subordinate relationships outside the sessions may limit

discussion. If such problems are anticipated, Nominal Group Technique (NGT, page 14) may be a better method to employ.

2) Initial use of the Synectics method may not be productive. However, experience with trial problems increases the effectiveness of the method.

REQUIRED RESOURCES

LEVEL OF EFFORT

A Synectics session includes eight to twelve members. They must meet and be organized into a group session. Participants must be made familiar with the technique. It is often possible in organizations to arrange a pool of potential members for Synectics sessions. This will minimize the effort required to arrange any one Synectics meeting.

SKILL LEVEL

A Synectics group usually includes one or two technical experts in the problem area. Other members should be able to fantasize, empathize, and role play. The group leader needs a thorough understanding of the technique, as well as some training as a session leader.

TIME REQUIRED

Most problems require only one session lasting at most four hours. The novelty of the problem situation and the variety in the background of the members affect the length of the session. Progress is also affected if group members are inexperienced or overly inhibited.

DESCRIPTION OF TOOL

DEFINITIONS

1) *Personal analogy* is used in Synectics sessions where a group member identifies with an element of the problem and looks at it as though he were that element. For example, if the problem is to develop inexpensive ways to dry and store grain in a wet climate, a member identifies with a single grain in a storage bin.

2) *Direct analogy* compares the problem being faced to a parallel situation in another field, technology, or discipline. For example, the grain storage problem may be compared to a bacterial colony whose propagation is to be controlled against disturbances in moisture and airflow.

3) *Symbolic analogy* describes the problem by objective and impersonal titles. These titles are used to identify other problems which may be described by the same title. They are generally expressed in two words, usually describing two conflicting attributes of the problem. For example, the grain storage problem may use "Crowded Separation" to describe the facets of the problem that of packed storage and that of sufficient grain separation to allow for airflow.

4) *Fantasy analogy* is the participant's wishful thinking that the problem may solve itself or cease to exist. For example, in the grain storage problem, one fantasy analogy may be that "Grains do not germinate, even if stored moist." This leads to the idea of irradiating the grain in order to cease germination.

REQUIRED INPUTS

1) A statement of the problem is necessary. For example, "Grains must be dried and stored economically in a poor region where the climate is wet."

2) Participants in a Synectics session are experts concerned with the problem, along with six to eight other members preferably from a variety of disciplines.

TOOL OUTPUT

1) A restatement of the problem definition can be expected. In the grain storage problem, the restatement may be, "It is required to store grain so that it does not spoil."

2) A Synectics session results in a number of possible solutions to the problem, e.g., "irradiate grain and store in any ordinary place," "store with bags of chemicals that absorb moisture," or "plant crop so that the harvest is in a dry season." The merits of each solution may then be evaluated for feasibility.

IMPORTANT ASSUMPTIONS

People vary greatly in their ability to utilize analogies, and consequently, their contribution to a Synectics group will differ markedly. The assumption behind Synectics is that cross-fertilization of ideas will lead to innovation and creative responses.

METHOD OF USE

GENERAL PROCEDURE

A Synectics session has basically two phases. The first phase is to introduce the problem to the group and obtain a redefinition of the problem. The second phase utilizes four analogy methods to generate possible solutions. It is sometimes necessary to identify new and related problems that must be solved before the original problem solution can be attempted.

The following is a guide for the Synectics leader.

1. **Define the problem.**
   Present the problem to the group. Have a technical expert or the decision maker briefly explain and analyze the problem.

2. **Purge ideas and criticisms.**
   2.1 Ask that the members suggest any solutions or ideas immediately after the presentation of the problem.
   2.2 Have the experts discuss the feasibility and suitability of these ideas as they are suggested. This gives participants a better and deeper understanding of the problem.

3. **Restate the problem.**
   3.1 Ask the participants to propose restatements of the problem.
   3.2 Select one definition that seems most acceptable to participants.

4. **Use direct analogies.**
   4.1 Ask evocative questions to generate a number of direct analogies by drawing from similar problems in other fields.
   4.2 Choose one analogy for further exploration.

5. **Use personal analogies.**
   5.1 Request some members of the group to play the roles of some elements of the problem. The elements may be animate or inanimate. For example, participants might be asked to be trees and examine the problem of preventing forest fires. Ideas and feelings expressed by participants may trigger solutions to the problem.
   5.2 It may be necessary to ask questions of participants to generate further insight into the problem.

6. **Use symbolic analogies.**
   6.1 Ask participants to generate symbolic titles for the problem. Such titles should be expressed in two words, usually describing two conflicting attributes of the problem.
   6.2 Select one analogy and have members explore it.

7. **Use fantasy analogies.**
   7.1 Suggest some physical or theoretical impossibilities related to the problem that may eliminate or simplify the problem.
   7.2 Let participants suggest other fantasy analogies. These ideas often generate possible solutions.

8. **Force fit some analogies.**
   8.1 If the analogies do not directly aid in solving the original problem then "force fit" an analogy.
   8.2 State some aspect of the problem and then apply it directly to the analogy to provide greater insight into the constraints and circumstances of the problem situation. For example, stored grain germinates if it gets wet. What would happen to a bacteria culture (force fit to direct analogy)?

9. **Repeat necessary steps.**
   9.1 Generate analogies (steps 4-7) in any convenient order. It may be necessary to use one or more of these analogies during the discussion.
   9.2 Direct the group into using these analogies in combination or to help the members force fit an analogy.

10. **Redefine the problem or present the solutions.**
   10.1 Determine if the results of the session are satisfactory. If not, it may be necessary to go back to step 3 and redefine the problem. Sometimes other related problems may be identified which should first be solved.
   10.2 Present the summarized results to the group and call the session to an end.

EXAMPLE

The following example gives some excerpts from the discussion in a Synectics session. The steps are identified in parentheses.

LEADER: We want to develop ranking or rating procedures for illiterate or semi-literate decision making [illegible] client groups (**Problem as Given**). The leaders of these groups would be literate. The group is to choose between different alternatives. As an example, a group might choose between different modes of health care delivery.

PETER: Have the leader explain alternatives orally to the group and associate a symbol with each alternative. Let the group order the symbols to show their choices (**Purge**).

EXPERT: But the members may not be able to retain the associations (**C[illegible]ism of Ideas during Purge**).

LEADER: Pat, if you [illegible]re illiterate and if Peter's method were adopted [illegible] would you do? (**Personal Analogy**) Peter, wh[illegible] [illegible]monstrate the method.

PETER: I've given sy[illegible] of the alternatives, Pat. Now choose the sym[illegible] [illegible]icates your choice of alternatives.

PAT: I am confused. I don't remember the symbol for one of the alternatives (**Personal Analogy**).

PETER: We could try choosing between two symbols at a time.

EXPERT: There is a problem though. Someone might choose B before A, C before B, C before A? The preferences are not transitive.

LEADER: Okay, let's consider another situation. There is a pet, say a cat. You want to communicate to it that it can choose only one kind of pet food (**Direct Analogy**).

RAJA: Make the cat taste a little from each container and find out which it prefers.

PAT: What if there are six types of pet food. It may have forgotten how the first type tasted.

PETER: Also there is the problem that the cat might be influenced by the order in which it is given the food. Hence the order that the alternatives are presented might be important.

LEADER: Okay, here we have a group of people who have to choose a health care plan. They look up to the leader. They want to please him, and they know he will only let them choose one plan. At the same time, they would like any or all of them.

PAT: You mean the cat is hungry and would like all of the different foods.

RAJA: You have a situation where there are many alternatives and the group would like to have all of them (**Force fitting analogy from cat wanting all different foods**). But the choices are limited, and only one can be selected.

LEADER: How about the phrase "Plentiful restrictions" to describe this? (**Symbolic Analogy**)

JUZAR: I think I would like the phrase "Eagerness Obedience." You see, the cat is eager to eat it all but looks up to the owner. In the same way, the members respect the leader.

PETER: The problem might be that the members will understand the alternatives and know what they want. It is only needed to communicate that they have to make a choice.

JUZAR: They may not want to make a choice. Often this is true.

PAT: Quite true. They may not wish to make any choice. They may not like any, but do not wish to say so.

RAJA: Why does the leader want the members to choose? I want to fantasize that there is no problem. So there is no group meeting. The leader simply makes the choice (**Fantasy Analogy**).

LEADER: Let us try posing the problem this way. The leader just wants the members to rubberstamp his choice....

LEADER: Okay, this is what we concluded. The problem is not that of developing a rating procedure, but one of how to communicate that choice is actually being made by the members. So related questions of motive behind the meetings need to be resolved. For example, are members voting merely to rubberstamp the leader's choice? Are they there to make a democratic decision? Does the leader hope that letting members vote will mean easier implementation of the plan, etc.?

The result of this exercise was not a problem solution but a redefinition of the problem which brought to light various constraints on the rating system procedure (see also Rating Scale (RTS), page 29).

THEORY

Gordon (1961) gives a theoretical basis showing how the use of analogies stimulates creativity.

BIBLIOGRAPHY

Davis, J. A., and Scott, J. A. *Training Creative Thinking.* New York: Holt, Rinehart and Winston, 1971, pp. 143-61.

Gordon, W. J. J. *Synectics.* New York: Harper and Row, 1961.

Morphological Analysis

PREREQUISITE TOOLS

None.

USAGE

PURPOSE

Morphological analysis generates a large number of element combinations for further examination.

USES

Morphological analysis can be used to:

1) Analyze a problem systematically.

2) Develop alternative projects and programs.

3) Identify a number of possible future states in a problem situation.

KEY DEFINITIONS

1) An *element* is a part of a problem description, e.g., population, land use, and climate may be some of the elements in an agricultural policy program.

2) An *attribute* of a system includes the elements or components of the system and their relationships.

SHORT DESCRIPTION

Morphological analysis involves decomposing a problem into its elements, identifying a number of alternative attributes for each element, and synthesizing alternative solutions by combining the attributes in different ways. The attributes are written in the form of a matrix to simplify the process (see figure 1). The elements may describe a future environment, in which case the combinations will be different futures.

ADVANTAGES

1) A large number of possible solutions are generated.

2) The method's exhaustive nature decreases the likelihood of overlooking possible solutions. It often identifies solutions that may have been overlooked if other methods, such as Nominal Group Technique (NGT, page 14), were used.

3) Because the process of synthesizing alternative solutions in morphological analysis is systematic, the biases and prejudices held by the person using the tool are avoided while generating ideas.

LIMITATIONS

1) Large problems lead to a large number of elements and attributes. In such cases, morphological analysis leads to so many possible solutions that evaluation becomes unwieldy.

2) If any significant element in a problem is overlooked, the morphological analysis suffers accordingly. This is the major limitation of the technique: it does not ensure that all elements are specified. The systems defini-

FIGURE 1

Attributes for an Energy Policy Situation

ELEMENTS	ATTRIBUTES				
Energy Demand	Low Demand	High Demand			
Growth Rate	Zero Growth	Slow Increase	Rapid Increase		
Primary Source of Energy	Oil	Gas	Solar	Nuclear	Fuel Cell
Primary Use of Energy	Industrial	Household	Transportation		

tion matrix (SDM, page 67, or Tree Diagrams.TRD, page 74) may be useful in this regard.

REQUIRED RESOURCES

SKILL LEVEL

Knowledge relating to the problem area and the skill to decompose the problem into its elements are essential to use this approach effectively. The analyst requires the ability to recognize potentially interesting combinations.

TIME REQUIRED

The time required depends on the complexity of the problem and the number of elements identified. A simple problem may need less than a day. The time required increases very rapidly as more elements are identified.

DESCRIPTION OF TOOL

REQUIRED INPUTS

A statement of the problem is necessary, such as "Give possible descriptions of the energy situation in Temasek" or "A primary health care program needs to be developed."

TOOL OUTPUT

Morphological analysis results in a number of alternative solutions to the problem statement synthesized from combinations of attributes for the different elements identified as part of the problem situation. For example, a table with six elements and four attributes can have $(4)^6 =$ 4096 possible combinations. However, many of these combinations may be physically if not theoretically impossible or meaningless. The remaining feasible combinations represent the product of a morphological analysis. However, even illogical combinations may trigger feasible alternative solutions.

IMPORTANT ASSUMPTIONS

A problem or task is divisible into discrete elements, each of which has one or more alternative attributes. This is not a limiting assumption since the analysts may always define a problem in such a way that decomposition is feasible.

METHOD OF USE

GENERAL PROCEDURE

1. **Identify elements and their attributes.**

   1.1 Consider the problem as stated and think of the elements that are part of the problem situation. Many elements can be identified directly from the problem statement. For example, elements like "type of cattle," "method of raising," and "scale of industry" follow directly from "it is required to develop a meat packing industry." Each of these elements may be described by different attributes.

1.2 Generate as many attributes as possible. An attribute often comes to mind before the element. For example, the attribute "government subsidy" may lead to the element "source of revenue." Other attributes for the element are then identified, e.g., "private donations" or "lottery tickets."

2. **Develop the table of attributes.**
   2.1 Organize the elements and attributes into a tabular form (see figure 1).
   2.2 List one element per row with its attributes. The table will have as many rows as there are elements identified. Often, the process of filling in the table will suggest new elements or attributes. Include them in the table.

3. **Synthesize alternatives.**
   3.1 Select one attribute from each element row (see dashed line, figure 2).
   3.2 Combine the attributes to describe a particular alternative.
   3.3 Throw out combinations which are unfeasible or illogical.
   3.4 Examine the remaining combinations for possible problem solutions or feasible alternatives.

EXAMPLE

In order to develop an energy policy, a government decides to use contingency analysis (CGA, page 147). A number of possible future states need to be identified. Morphological analysis was used as follows:

Some of the elements are discovered immediately, e.g., "energy demand" and "source of energy." Other elements like "use of energy" and "rate of growth of economy" follow. A table for these attributes is given in figure 1. Alternative future states are synthesized from the table:

1) A situation of high energy demand with a rapid economic growth; the largest source of energy is oil used primarily in transportation (shown in figure 2).

2) A zero growth economy with low energy demand using solar energy primarily for household consumption. Eighty-eight other combinations were possible, though only a few were used in the contingency analysis.

FIGURE 2
One Combination of Attributes Indicated in a Morphological Chart

ELEMENTS	ATTRIBUTES				
Energy Demand	Low Demand	High Demand			
Growth Rate	Zero Growth	Slow Increase	Rapid Increase		
Primary Source of Energy	Oil	Gas	Solar	Nuclear	Fuel Cell
Primary Use of Energy	Industrial	Household	Transportation		

THEORY

Morphological analysis was developed by Zwicky (1969) and used extensively in a variety of contexts ranging from new product development to problem solving. Wissema (1976) reports an interesting application of the technique in technological forecasting, particularly emphasizing that morphological analysis could be used to construct scenarios (SCN, page 164) and Delphi questionnaires (DLP, page 168).

Kaufman (1968) deals with the problem of ranking the combinations of attributes to facilitate the selection of feasible alternatives. He explores the implications for decision theory. The parallel between the morphological box representation of a problem and interaction matrix diagrams should be clear from examining the format of the products of each technique (see IMD, page 92).

BIBLIOGRAPHY

Kaufman, Arnold. *The Science of Decision-Making*. New York: World University Library, McGraw-Hill, 1968, page 234-41.

Wissema, Johan, G. "Morphological Analysis: Its Application to a Company Technological Forecasting Investigation." *Futures* (April 1976): 146-53.

Zwicky, Fritz. *Discovery, Invention, Research Through the Morphological Approach*. Toronto, Canada: Macmillan, 1969.

Nominal Group Technique

PREREQUISITE TOOLS

None.

USAGE

PURPOSE

The Nominal Group Technique (NGT) is a group process for eliciting opinions and aggregating judgments to increase rationality and creativity when faced with an unstructured problem situation.

USES

NGT may be used to:

1) Identify the elements of a problem, especially where there are political, social, and cultural elements.

2) Identify and rank goals or priorities.

3) Identify experts whose experiences or skills may be useful in other decision-making techniques.

4) Involve personnel at all levels in the decision-making process in order to promote the acceptability of the final decision.

KEY DEFINITIONS

1) A *nominal group* is a group process in which the members work independently but in each other's presence.

2) An *interacting group* permits discussion between participants (e.g., Brainstorming, BSG, page 3, is an interacting group process).

3) *Rank-ordering* is the process of weighing one item against others and then ordering the items by weight on a scale such as importance or priority.

SHORT DESCRIPTION

The Nominal Group Technique is a structured process which taps the experiences, skills, or feelings of participants. A question is posed to the group. Each member writes down as many responses as possible. The group leader asks each member in turn to state an idea from his or her list and writes it on a flip chart placed before the group. No discussion is permitted until all ideas have been listed. Each item is then briefly discussed in an *interacting group* format. The participants indicate their preference for important items by *rank-ordering*, a process which may be repeated with intervening discussion and argument.

The outcome of the process is the mathematical aggregation of each member's preferences to give the group's ranking of responses to the question.

ADVANTAGES

1) Dominance by high-status, aggressive, or articulate members is reduced since each has an equal opportunity to participate.

2) The group remains problem-conscious: and premature evaluation, criticism, or focusing on ideas is avoided.

3) The silent generation of ideas minimizes the interruptions in each person's thought processes.

4) A written record increases the group's ability to deal with a large number of ideas. It also avoids the loss of ideas.

5) Discussion only to clarify items helps eliminate misunderstanding, without reducing the group's efficiency.

6) Some studies have shown that, compared to interacting group processes, e.g., Brainstorming (BSG, page 3), the Nominal Group Technique (NGT) enhances the conditions for creativity when generating information on a problem. It avoids rambling discourse and other deficiencies found in group processes.

LIMITATIONS

1) Cross-fertilization of ideas is diminished due to the structure imposed by the NGT.

2) The NGT may reduce flexibility, e.g., some group members may feel that the purpose of the meeting or the question posed is irrelevant or misleading, but they have no opportunity to change it.

3) Bringing group members together may be cost-prohibitive.

REQUIRED RESOURCES

LEVEL OF EFFORT

Some administrative effort is required to determine the purpose of the meeting and to structure the proposed question. Potential group members need to be identified, notified, and assembled.

SKILL LEVEL

The leader of the nominal group should not bias the group toward his view; yet he must control unwanted group behavior without alienating people.

TIME REQUIRED

In a study quoted by Delbecq, et al. (1975), the total administrative man-hours to prepare, conduct, and follow through for one group required an average of 4.4 hours for NGT, 4.2 hours for interacting processes, and 7.1 hours for the Delphi process (DLP, page 168).

SPECIAL REQUIREMENTS

A flip chart and marking pens are needed for each group. Index cards (or similar small cards), approximately six per participant, facilitate the voting process.

The seating arrangement must allow all members to easily focus on the ideas listed on the flip chart. Some means of displaying the completed chart pages is necessary (e.g., tacks or masking tape to afix them to the walls).

DESCRIPTION OF TOOL

SUPPLEMENTAL DEFINITION

Round-robin is a process for serially recording ideas where each participant provides an idea in turn. No discussion occurs, although the leader may ask for a show of hands on how many participants had a similar idea. (This is noted next to the item on the list.) Those responding then eliminate that idea from their respective lists. The process may continue in a circular fashion until all participants' lists are exhausted.

REQUIRED INPUTS

The nominal group generally includes five to nine members. Less than five members may not allow for the quality and diversity of opinions required. Large groups produce more interpersonal differences, which lengthens the process without a substantial increase in the quality of output. If more than ten persons must participate, it is better to divide the group for the round-robin and combine them for final discussion and voting.

The group leader may be directly involved in generating and discussing ideas. The composition of the group may be homogeneous or heterogeneous. Studies have shown that heterogeneous groups exhibit more creativity (Delbecq, 1975). But interpersonal differences and communication problems may increase for such groups.

The NGT question provides the basis for generating the ideas. It should be worded to prevent misunderstanding and should be stated as objectively as possible.

TOOL OUTPUT

The NGT produces a list of ideas and a rank-ordering of their importance. The group leader may wish to combine overlapping ideas under a common heading.

METHOD OF USE

GENERAL PROCEDURE

The general procedure for the Nominal Group Technique is straightforward. But because it runs counter to the experience of most people in leading groups or participating in committee work, the steps must be followed closely. With this in mind, the guidelines prescribed by the originators of the Nominal Group Technique have been reproduced below (Delbecq, et al., 1975, figure 3-7, page 67-69):*

1. Silent generation of ideas in writing.

1.1 Present the nominal question to the group in writing.
1.2 Verbally read the question.
1.3 Illustrate level of abstraction and scope desired with example which does not distort (lead) group responses.
1.4 Avoid other requests for clarification.
1.5 Charge the group to write ideas in brief phrases or statements.
1.6 Ask group members to work silently and independently.
1.7 Model good group behavior.
1.8 Sanction disruption of the silent, independent activity by comments addressed to group as a whole.

Benefits:

1) Provides adequate time for thinking.
2) Facilitates hard work by the model of other group members reflecting and writing.
3) Avoids interruption of each other's thinking.
4) Avoids premature focusing on single ideas.
5) Eliminates dominance by high-status or aggressive members in idea generation.
6) Keeps the group problem-centered.

2. Round-robin recording of ideas on a flip pad.

2.1 Indicate objective of the step is to map the group's thinking.
2.2 Explain need to present ideas in brief words or phrases.
2.3 Explain process of taking one idea serially from each member.
2.4 Explain group members must decide if items are duplicates.
2.5 Explain that an individual may "pass" when he has no further items, but may "re-enter" later.
2.6 Express the desirability of hitchhiking and adding new ideas even if they are not on individual nominal worksheets.
2.7 Explain inappropriateness of discussion prior to completion of listing.

*From *Group Techniques for Program Planning* by André L. Delbecq, Andrew Van de Ven and David H. Gustafson. Copyright (c) 1975 by Scott, Foresman and Company. Reprinted by permission.

2.8 Record ideas as rapidly as possible.
2.9 Record ideas in the words used by group members.
2.10 Provide assistance in abbreviating only in special situations.
2.11 Make the entire list visible by tearing off completed sheets and taping them on an area visible to all group members.
2.12 Sanction group as a whole if individuals engage in side conversations or attempt to discuss items prior to completing the listing.

Benefits:

1) Equalizes opportunity to present ideas.
2) Assists in separating ideas from personalities.
3) Provides a written record and guide:
   a) Increases group's ability to deal with a larger number of ideas.
   b) Avoids loss of ideas.
   c) Confronts the group with an array of clues.
   d) Encourages hitchhiking.
4) Places conflicting ideas comfortably in front of group.
5) Forces the group to fully explore the problem.

3. Serial discussion for clarification.

3.1 Verbally define the purpose of the step:
   a) To clarify the meaning of items.
   b) To explain reasons for agreement or disagreement.
3.2 Indicate that final judgments will be expressed by voting, so arguments are unnecessary.
3.3 Pace the group so that all ideas receive sufficient time for clarification.
3.4 Avoid forcing the member who originally lists the idea to be solely responsible for clarifying the item.

Benefits:

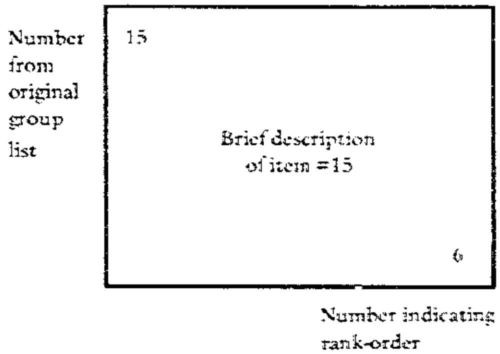
1) Avoids having discussion focus unduly on any particular idea or subset of ideas.
2) Helps eliminate misunderstanding.
3) Provides opportunity to express the logic behind items.
4) Allows members to disagree without argumentation.

4. Preliminary vote on item importance.

4.1 Ask the group to select from the entire list a specific number (7 ± 2) of priority (important) items.*

*Five to nine items are all that can be effectively ranked on one dimension of discrimination (see Rating Scales, RTS, page 29).

FIGURE 1
Index Card Illustrating Rank-Order Voting Process



4.2 Place each priority item on a separate 3 x 5 card or rating form [see figure 1].
4.3 Rank-order or rate the selected priority items.
4.4 Collect the cards or rating forms and shuffle them to retain anonymity.
4.5 Tally the vote and record the results on the flip chart in front of the group.

Benefits:

1) Obtaining independent judgments in writing helps eliminate social pressures.

2) Expressing judgments mathematically by rank-ordering or rating increases accuracy of judgments.

3) Displaying the array of individual votes clearly highlights areas needing further clarification or discussion.

5. Discussion of the preliminary vote.

5.1 Define the role of the step as clarification, not pressure toward artificial consensus.
5.2 Keep the discussion brief.
5.3 Caution group members to think carefully about any changes they make in their voting.

Benefits:

1) Provides group members a final opportunity to clarify their positions.

2) Ensures that "spread" votes really reflected differences in judgment, not unequal information or misunderstanding.

6. Final vote.

6.1 Repeat step 4.
6.2 Closure to the meeting.

Benefits:

Accurate aggregation of group judgments and error reduction.

EXAMPLE

The steps of the Nominal Group Technique have been presented in a straightforward procedure which reflects a structured group process. The following example highlights some of the key points in this process and illustrates typical intermediate products generated by the technique.*

The Ministry of Health for the government of Temasek wanted to analyze the state of the health delivery service. The evaluation staff elected to use the Nominal Group Technique and brought together a diverse group of physicians, rural health technicians, public health personnel, field personnel, and a cross-section of clients (from different income and social classes).

Silent Generation of Ideas in Writing

The assembled participants were broken into groups of nine by randomly selecting participants representing relevant occupations.

After the opening welcome and a brief explanation of the Nominal Group Technique and the objectives for the afternoon, each participant was given a single sheet headed with the following question:

WHAT ARE THE BARRIERS TO RECEIVING ADEQUATE HEALTH CARE IN OUR COUNTRY?

The participants were allowed 15 minutes to list responses from their own viewpoints.

Recording of Ideas on a Flip Pad

The leader for each group (a member of the evaluation staff trained in NGT) acted as the recorder to serially list the ideas. Some of the ideas generated by one group included:

1) No money to pay for services
2) Lack of adequate facilities
3) Too many doctors in the cities
4) Not enough trained personnel
5) Over reliance on traditional remedies
6) Not enough doctors

Note that this list contains some contradictions. The leader deferred discussion until the next step. However, when item 6 was voiced, someone asked whether this was the same as item 4 since doctors are included in trained personnel. The leader asked the participant if he thought item 6 should be dropped. The reply was negative, and the round-robin recording continued. All of the groups generated 15 or more items.

*This example is adapted from an exercise conducted by one of the authors at a workshop to enable county health agencies to plan for the treatment of alcoholics.

Serial Discussion for Clarification

During the discussion of each item, the participants clarified their responses, e.g., since trained personnel can replace many functions of the physician, items 4 and 6 deserved separate consideration. Item 5 included going to a traditional village healer instead of the nearest clinic.

Preliminary Vote on Item Importance

Each participant was asked to rank (from the list) the five most significant barriers to receiving adequate health care. The tally of the vote was recorded on the flip chart, using the numbers from the items. A vote of five meant that the participant viewed that item as the most significant barrier. The votes for the first six items were:

Item Number	Votes	Total
1)	4, 1	5
2)	5, 4	9
3)	2, 2, 4	8
4)	3, 5, 3	11
5)	1	1
6)	3, 5	8

Discussion and Final Vote

During the discussion following the first vote, the participant who had presented item 5 expressed his amazement that the other members had not found the interference of superstitions and traditional healers to be a barrier. Other participants were not swayed by his arguments, and the final vote on the item was unchanged. Totaling the individual rankings for each of the above items gave item 4 the most weight (11) followed by item 2 (9) and item 6 (8). Note that this example is incomplete since the rest of the list has not been presented, but the essential idea remains the same. A group with rather large status differences was able to use the Nominal Group Technique to identify and rank problems in receiving health care.

THEORY

The Nominal Group Technique is the result of analysis and experimentation with group processes for effective planning and decision making, and is credited to Van de Ven and Delbecq (Delbecq, et al., 1975). The creativity of a group is an important determinant of its success. Types of group processes and leadership techniques for allowing creativity have been discussed widely (Maier, 1970: Osborn, 1957: Collins and Guetzkow, 1964).

The Nominal Group Technique utilizes the mathematical aggregation of group judgments to come to a group decision. The theory is discussed by Huber and Delbecq (1972). The advantages over conventional means for coming to a group decision (e.g., consensus or majority rule) are described by Delbecq, et al. (1975).

BIBLIOGRAPHY

Collins, B. E., and Guetzkow, H. *A Social Psychology of Group Processes for Decision-Making.* New York: John Wiley & Sons, 1964.

Delbecq, André; Van de Ven, Andrew; and Gustafson, David. *Group Techniques for Program Planning: A Guide to Nominal Group and Delphi.* Chicago: Scott Foresman, 1975.

Huber, George, and Delbecq, André. "Guidelines for Combining the Judgment of Individual Members in Decision Conferences." *Academy of Management Journal* 15 (June 1972): 161-74.

Maier, Norman R. F. *Problem Solving and Creativity in Individuals and Groups.* Belmont, Calif.: Brooks/Cole, 1970.

Osborn, A. F. *Applied Imagination.* New York: Charles Scribner's Sons, 1957.

Questionnaires

PREREQUISITE TOOLS

None.

USAGE

PURPOSE

Questionnaires generate ideas, opinions, or information from a selected target population.

USES

Questionnaires are used to:

1) Structure the content of an interview (Interviews, IVW, page 23).

2) Obtain responses for a sample survey (Surveys, SVY, page 36).

3) Provide the format for communicating with Delphi participants (Delphi, DLP, page 168).

KEY DEFINITIONS

1) *Open questions* permit the respondent to answer as he or she chooses.

2) *Closed questions* require the respondent to limit responses to prespecified categories, e.g., Yes/No, Option A, B.

3) *Frequency distributions*, or histograms, plot the frequency of different categories of response (see Histograms, HIS, page 131).

SHORT DESCRIPTION

Questionnaire design is an art with scientific elements determined by the purpose of the questionnaire, the type of responses desired, the characteristics of the respondent, and the method of distribution. Questionnaires may be distributed by mail, by phone, or directly. The responses may be obtained from a direct interview or by a self-administered questionnaire which is then collected (e.g., by return mail). The length and format of the questionnaire are crucial factors affecting the return rate, the validity of responses, and unintentional biases or distortion.

ADVANTAGES

1) Self-administered questionnaires allow the participant time to ponder the questions.

2) Mailed questionnaires may be distributed to a population at less cost than interviews.

3) Phone questionnaires involve minimum cost and maximum speed of response.

4) The anonymity of the respondents may be ensured.

LIMITATIONS

1) The return rate for mailed questionnaires is usually very low.

2) Those who do return the questionnaire may share a common interest that biases the sample.

3) Distribution by mail is often impractical because of reliability and time constraints.

4) Self-administered questionnaires are rigid and inflexible—confusion and ambiguities cannot be clarified by an interviewer.

5) Self-administered questionnaires can't be employed for illiterate or semi-literate populations, and may lead to erroneous responses for literate but mixed-culture target groups.

REQUIRED RESOURCES

LEVEL OF EFFORT

By far the greatest effort must go into designing and testing the format of the questionnaire. Other tasks, such as distribution and analysis, are proportional to the number of respondents, the number of open-ended questions, and the length of the questionnaire.

SKILL LEVEL

Questionnaire design requires skills which are only gained by experience. It is impossible to anticipate the misinterpretations and personal logic in responses; therefore, pretesting the questionnaire is important to success.

TIME REQUIRED

A comprehensive questionnaire design might take several days. Time must be allowed for pretesting, distributing the questionnaires (or interviewing), and analyzing results. Allowing time to encourage returns of mailed questionnaires is essential if the return rate is to be reasonably high.

SPECIAL REQUIREMENTS

The necessity to duplicate and assemble the questionnaire copies must not be ignored. Manual analysis of responses can be tedious, and electronic computation equipment (including specially programmed digital computers) is a great relief. Where such means are cost-effective, the response format should be designed with computer coding in mind.

DESCRIPTION OF TOOL

REQUIRED INPUTS

Questionnaire design begins with the purpose and target population clearly identified (see Surveys, SVY, page 36).

Mail facilities and self-addressed stamped envelopes are essential for mailed questionnaires. Include a cover letter describing the purpose and details of the questionnaire, even if the target population has been previously informed. For example, Delphi participants are involved in a series of questionnaires which are returned in a two-way communication (see Delphi, DLP, page 168).

TOOL OUTPUT

Individual questionnaires are not the end product of questionnaire design—the aggregated responses of the participants is desired. Consequently, an incomplete or mutilated questionnaire that is returned is valid information for the analyst.

Decision makers demand information in an easily digested form. This includes summaries of typical responses as well as indications of the pattern of responses, e.g., a graph of the frequency of categorical responses (see Histograms, HIS, page 131).

Usually the questionnaire results will be an intermediate product in further analysis which may or may not be transmitted to decision makers. But most of the time it will be appended to a final report (see Surveys, SVY, page 36, and Delphi, DLP, page 168).

IMPORTANT ASSUMPTIONS

A questionnaire is a measuring instrument. It is a transmitter of information from a selected individual to an analyst. The responses must be accepted at face value in the absence of any other information. Therefore, the analyst assumes that responses were given by the selected individual, that the responses were freely given, that the respondent was not just trying to please him, etc. Some of these necessary assumptions may be validated by randomly spot-checking returned questionnaires, e.g., by direct interview or phone.

METHOD OF USE

GENERAL PROCEDURE

1. Specify the purpose of the questionnaire.
   1.1 Identify the topics to be covered—keep the number to a minimum.
   1.2 Identify the target population and any special cultural or educational characteristics it might have.
   1.3 Determine the means of distribution and collection of the questionnaire.
   1.4 Specify an acceptable return rate and adjust the sample number of questionnaires accordingly. A

return rate for mailed questionnaires may be anywhere from 15% to 90%, depending on the motivation of the respondents and the topics selected.

2. Design the questionnaire (Phillips, 1966).
   2.1 Start with basic information about the respondent; consider only that information essential for analyzing the results. Ensure anonymity if desired.
   2.2 On any topic, begin with general questions. Then get more specific.
   2.3 Arrange the questions logically and avoid abrupt transitions.
   2.4 Examine the order for questions which may exert an undesired influence on the response to subsequent questions, e.g., a question which is likely to antagonize the respondent should be placed near the end of the questionnaire.
   2.5 If necessary, code the questionnaire so that responses and participants may be correlated, e.g., arrange questions in different sequences.

3. Edit each question after completing the list.
   3.1 Avoid long questions.
   3.2 Eliminate ambiguities and double entendres by incorporating examples or by setting the question in context.
   3.3 Determine if an open-ended question can be rewritten as a closed question.
   3.4 Make certain that the categories of response for closed questions are sufficiently comprehensive, e.g., by including a "none of the above" category.
   3.5 Eliminate emotionally charged words and leading or loaded questions.

4. Design validating questions into the survey.
   4.1 Repeat the same question (rephrased) at a later point in the questionnaire.
   4.2 Include collaborating questions where memory or personal biases are likely to influence the response, e.g., "How many bushels per acre did your last crop yield?" may be followed by a question "What was the tax on your harvest?"

5. Pretest the questionnaire.
   5.1 Try the questionnaire out on fellow staffers and analyze the results to see whether the desired information has been elicited.
   5.2 Administer the questionnaire to one or more members of the target population, checking particularly for cultural or educational anomalies.

6. Distribute the questionnaire.
   6.1 Include a cover letter in a mailed questionnaire.
   6.2 Include a self-addressed stamped envelope.
   6.3 Arrange for collection points for self-administered questionnaires and pick them up on schedule.
   6.4 Provide transportation for direct interviews (see Interviewing, IVW, page 23).

7. Analyze the results.
   7.1 Begin the analysis as soon as the first questionnaire is returned.
   7.2 Summarize the answers to open questions by listing the main points and the similarities or differences in responses.
   7.3 Aggregate the responses to closed questions and tabulate the frequencies in order to prepare a histogram (Histogram, HIS, page 131).
   7.4 Prepare a final report for transmission, including the original questionnaire as an appendix.

EXAMPLE

The following questions were taken from a questionnaire designed to elicit basic data on farm wages as part of a cost-benefit analysis (CBA, page 212). The target population is the farmers along the Mai River in the country of Temasek.

1. Name (optional) ______________________
2. Address (optional) ______________________
3. General location of farm (check one):

   ☐ north of Mai River
   ☐ south of river
   ☐ north of village
   ☐ south of village

4. Size of farm:

   ☐ smaller than one hectare
   ☐ between one hectare and two hectares
   ☐ larger than two hectares

5. Number of farm workers (including members of family) ____________
   Available at harvest time? ________

6. Did you hire farm labor this year?
   Yes ____ No ____

7. If yes, how much did you pay?
   per hour? ____ per day? ____

8. How many did you hire? ________

The questionnaire begins with general (neutral) questions. Question 3 is a closed question whereas question 5 is open (but quantified).

If the number of farm workers needs to be cross checked, the questions on members of the family available for farm work can be used. However, even such relatively straightforward questions can lead to unreliable responses. How does the farmer define "family"? Is the extended family included? A careful pretest would probably result in a better specification of these questions.

THEORY

The theory of questionnaire design is documented in a number of texts addressed to survey research (Festinger and Katz, 1953; Warwick and Lininger, 1975). The theory is based on numerous empirical studies including the effects on the return rate of factors such as different questionnaire layouts, the color of paper, or the length of the questionnaire. However, there is no substitute for experience (including pre-testing): each situation is unique.

BIBLIOGRAPHY

Clover, Vernon T. *Business Research: Basic Principles and Techniques*. Lubbock, Texas: Rodgers Litho, 1958, pp. 101-72.

Festinger, L., and Katz, D. *Research Methods in the Behavioral Sciences*. New York: Holt, Rinehart and Winston, 1953.

Phillips, Bernard S. *Social Research: Strategy and Tactics*. New York: Macmillan, 1966, pp. 107-24.

Warwick, Donald P., and Lininger, Charles A. *The Sample Survey: Theory and Practice*. New York: McGraw-Hill, 1975.

Young, Pauline V. *Scientific Social Surveys and Research*. Englewood Cliffs, N.J.: Prentice-Hall, 1956, pp. 176-204.

Interviews

PREREQUISITE TOOLS

Questionnaires (QTN, page 19).

USAGE

PURPOSE

An interview generates ideas and gathers information by posing relevant questions to the respondent(s).

USES

Interviewing is useful for:

1) Obtaining background information about a problem situation.

2) Collecting information and ideas from a selected sample within a target population (see Surveys, SVY, page 36).

3) Eliciting information and ideas from experts or professionals, e.g., agency representatives.

KEY DEFINITION

An *interview schedule* is the plan for conducting an interview. It includes the questions to be posed.

SHORT DESCRIPTION

Interviews involve interpersonal transactions. The preparation, conduct, and results of the interview are determined largely by the participants. The interviewer may be specially trained. The *interview schedule* may be structured (*closed questions*) or unstructured (*open questions* and discussion). The respondent may be a professional, a project participant, or a randomly selected member of a target population. The combination of these factors is dictated by the purpose of the interview and the topic of inquiry.

ADVANTAGES

1) An interview provides a degree of flexibility in obtaining information and generating ideas that is not likely to occur in impersonal transactions, e.g., a mailed questionnaire.

2) The questions may be adapted during the course of the interview in response to immediate feedback from the respondent.

3) Face-to-face interaction tends to heighten the respondent's interest in participation and forces him or her to consider the questions immediately.

4) Where information must be gathered from an illiterate or semi-literate population, interviews may be the only effective instrument.

5) The interviewer can use cues other than the content of responses to assess their validity.

LIMITATIONS

1) When several people have to be interviewed on similar topics, or where a wide range of issues has to be

covered, the necessary resources may be cost-prohibitive when compared to using questionnaires (QTN, page 19).

2) An interviewer without the necessary skills may alienate the respondents or allow him or her to dominate the exchange.

3) Where the respondent is not motivated, the answers are likely to be inadequate.

4) If creativity or the discussion and evaluation of ideas are required, group processes such as Nominal Group Technique (NGT, page 14) or Brainstorming (BSG, page 3) may be more appropriate.

5) The anonymity of respondents (and thus their candor) cannot be ensured.

REQUIRED RESOURCES

LEVEL OF EFFORT

Gathering information by direct interviews can be a major effort bounded by the amount of information sought and the number of interviews desired. A follow-up interview may be necessary. Special training is required for interviewers.

SKILL LEVEL

An interviewer must have certain skills to ensure proper and effective interaction (Bocchino, 1972):

1) Training to recognize his/her own prejudices in order to maintain an open mind.

2) Giving credit wherever due and publicly acknowledging help.

3) Emphasizing courtesy and respect.

4) Respecting the skills of the respondent.

5) Listening more than talking.

TIME REQUIRED

Preparing for an interview takes about a day. An interview lasting longer than an hour usually results in diminishing returns. Time must be budgeted to write the interview report.

SPECIAL REQUIREMENTS

Electronic recording (audio or video) of questions and responses can be a great time-saver and can allow the interviewer to give full attention to the responses. However, there are some costs, such as transcription expenses and the possible loss of candor by the respondent. If electronic equipment is to be used, the respondent's prior permission is essential.

Ideally, the interview should take place in a location free from distraction (noises, telephone calls, children or other onlookers, etc.). One technique used in a village household survey in India was to provide a highly visible distraction in the center of the village while the interview team discretely circulated among the houses.

DESCRIPTION OF TOOL

REQUIRED INPUTS

The purpose of the interview must be established and should guide subsequent decisions. If the interview is the measuring instrument for a sample survey (SVY, page 36), the target population will have been selected and a questionnaire designed (QTN, page 19).

If the interview seeks ideas and information from experts in different fields, the preparations and the training of the interviewer will differ. In all cases, however, the purposes must be established in advance.

TOOL OUTPUT

An interview usually results in a report or tabulated responses which may be analyzed and transmitted to decision makers. The data may be in the form of a histogram (HIS, page 131), a statement of preferences, etc. Often, the report will be strengthened by including illustrative responses to key questions, but unprocessed responses are seldom useful.

IMPORTANT ASSUMPTIONS

The interviewer is assumed to be an unbiased, noninteractive transmitter of information and ideas. Where this is not the case (either by design or circumstance), the information must be appropriately interpreted. For example, the manner and style of the interviewer may trigger more negative (or positive) responses than expected for a neutral reporting instrument (e.g., a self-administered questionnaire).

METHOD OF USE

GENERAL PROCEDURE

The following steps are useful guidelines for planning and conducting an interview.

1. Specify the purpose of the interview.

2. Determine who is to be interviewed.

3. **Prepare an interview schedule.**
   3.1 Design the questionnaire and determine the type of responses to be allowed (Questionnaires, QTN, page 19).
   3.2 Determine how the responses are to be recorded and, if necessary, develop a coded form.
   3.3 Make provisions for transcribing electronically recorded interviews (optional).

4. **Select and train interviewers (optional).**
   4.1 Select interviewers based on the types of respondents.
   4.2 Train interviewers to eliminate biases and provide for uniform reporting.
   4.3 Pretest all questions and anticipate ambiguities.

5. **Conduct the interviews.**
   5.1 Arrange for transportation.
   5.2 Notify respondents in advance (optional).
   5.3 Arrange for immediate collection of reports.

6. **Synthesize and analyze the responses.**
   6.1 Begin immediately to eliminate ambiguous responses in case corrections are necessary.
   6.2 Report the overall results in a form suitable for transmission to others (e.g., consider such factors as anonymity of respondents, biases of interviewers, and systematic distortions in responses).

EXAMPLES

Rather than present the protocol of an interview, the following examples describe recommended procedures for conducting two very different kinds of interviews.

Interviewing a Peasant Population for an Aid Project

The following considerations were recommended by a colleague with extensive field experiences in data gathering (Ingersoll, 1976).

1. Entry

If the interview is not simply an academic pursuit of knowledge but project centered, the participant will have a much greater incentive to participate. Factors to consider in planning the interview include: cultural values, the influence of the extended family, outsiders sitting in on the interview, and differences in perceptions of space, time, and quantity.

2. Respondent in center

Make the respondent the center of attention during the interview. Be sensitive to participants who need cues to continue. Pay attention to answers. Don't divert attention to the mechanics of filling out forms.

3. The interviewer's posture

The ideal is neutrality, although it may be necessary to be positive to the respondent's views in order for the interview to proceed. Receive all replies with interest. Avoid body English, e.g., nodding. Engage in active listening, e.g., repeating exactly what the person says. Decide how to handle confusion over a question, e.g., rephrasing a question or giving an example. Note any further probe into a question for inclusion in the report of the interview.

4. Departure

Make sure that the respondent is not left with false impressions, e.g., that a new road *will be built* as an immediate result of his participation. Give some praise if new information and ideas have been volunteered. Signal the end of the formal interview, e.g., closing up the clipboard. Observe the social amenities upon departure, e.g., small talk. One may have to come back with more questions.

Interviewing a Professional or a Decision Maker

The situation is far different when the respondent occupies a status position in an academic, business, or governmental organization. Hartman (1968) recommends the following steps for a successful interview:

1. **Prepare for the interview.**
   1.1 Research the background of the respondent to become familiar with any special terminology or jargon.
   1.2 Schedule the interview well in advance to allow the respondent time to prepare.
   1.3 Arrange the interview through the respondent's immediate superior (where this is feasible) to assure the respondent that his participation is important and approved.
   1.4 Get the respondent's correct name and title in advance.
   1.5 Avoid scheduling interviews for late in the day, just after mealtime, or just before a weekend.

2. **Conduct the interview.**
   2.1 Introduce yourself and clarify the purpose of the interview even if there has been prior notification.
   2.2 Keep the interview to the subject—respect the demands on each other's time.
   2.3 Start the interview with broad questions.
   2.4 If the responses are not satisfactory, emphasize the importance of the respondent's views for the decision-making process.

2.5 Allow the respondent to think during occasional periods of silence.
2.6 When a reply is unclear, ask the respondent to separate opinions from facts.
2.7 Don't let note-taking interrupt the normal flow of discussion; use abbreviations and symbols or electronic recording (with prior permission).
2.8 Conclude the interview by allowing a few minutes for informal conversation and summation. Often these comments may divulge useful information and may give an indication of the validity or sincerity of the previous responses.

3. Follow up the interview.
   3.1 Prepare the report of the interview immediately.
   3.2 If a follow-up interview is necessary, send the report (or a digest of the first interview) to the respondent in advance.
   3.3 In all cases, send a formal thank you to the respondent and his supervisor acknowledging their cooperation.

THEORY

There is no theory of interviewing in the sense of general laws or "truths." Each interview is different. However, there is some merit to taking a systems approach to the design of an interview, particularly when used as the measuring instrument for sample surveys (Surveys, SVY, page 36).

An interview is analogous to a communication system having four principal components (Warwick and Lininger, 1975, p. 184):

The interviewer
The respondent
The study content or topic
The interview situation

Each of these factors interact to determine the efficiency and effectiveness of the interview. The efficiency concerns the amount of information gathered per unit of time and cost. The effectiveness relates to the usefulness of the ideas or information gathered. For example, the interviewer and/or the respondent can introduce both biases and distortion into the information gathered. Consequently, if interviewing is to be an effective technique, the specification of any one of the components must take into account the interaction with the other factors, i.e., designed as an information-gathering system (Hartman, et al., 1968).

BIBLIOGRAPHY

Bocchino, William A. *Management Information Systems: Tools and Techniques*. Englewood Cliffs, N.J.: Prentice-Hall, 1972, pp. 83-84.

Hartman, W.; Matthes, H.; and Proeme, A. *Information Systems Handbook*. Apeldoorn, The Netherlands: N.V. Philips-Electrologica, 1968. Section 6-3.1, pp. 1-10.

Ingersoll, Jay. "Lecture to Development Studies Program." U.S. Agency for International Development, Washington, D.C., Spring 1976.

Kahn, R.L., and Cannell, C.F. *The Dynamics of Interviewing: Theory, Techniques and Cases*. New York: John Wiley and Sons, 1966.

Warwick, Donald P., and Lininger, Charles A. *The Sample Survey: Theory and Practice*. New York: McGraw-Hill, 1975.

II
Assessing Qualitative Factors

Rating Scales
Multiple Criteria Utility Assessment
Surveys
Organizational Climate Analysis

There is a danger in project design and systems modeling of overlooking a factor because it is not in quantitative form. Techniques for assessing qualitative factors are essential to a systems approach, and four such techniques are described. Two are scaling procedures (Rating Scales and Multiple Criteria Utility Assessment). The other techniques are broadly based assessment procedures (Surveys and Organizational Climate Analysis). All four provide a means of transforming qualitative attributes into quantitative measures, though clearly the latter two have a variety of uses.

Rating Scales

PREREQUISITE TOOLS

None.

USAGE

PURPOSE

A rating scale measures the degree to which an entity possesses or exhibits a specified property, as either an absolute or a relative judgment.

USES

Rating scales are used to quantify factors which may be highly subjective or qualitative in nature. Once the judgment is scaled, the quantitative measure may be incorporated into analyses such as:

1) Rating the individual utilities of various criteria using Multiple Criteria Utility Assessment (MCU, page 32).

2) Evaluating alternative decision sequences in a decision tree (DTR, page 141).

3) Evaluating alternative plans, given various contingencies which may be expected to occur (Contingency Analysis, CGA, page 147).

4) Ranking alternatives as in Nominal Group Technique (NGT, page 14) and Delphi (DLP, page 168).

KEY DEFINITIONS

There are four primary types of rating scales (see figure 1):

1) *Nominal scales* simply categorize different factors, e.g., hot/cold, dark/light, and black/gray/white represent nominal scales for heat, illumination, and color.

2) *Ordinal scales* are used to rank-order a set of similar objects along a criterion dimension which reflects a basis for comparison, but not the degree of difference, e.g., warm, warmer, hot, hotter, hottest are ordinal rankings of heat sensation.

3) *Interval scales* reflect not only the rank of one factor over another, but the degree to which one exceeds the other. The difference between them corresponds to a length of scale interval. The zero point is arbitrary.

4) A *ratio scale* is an interval scale for which the dimension of comparison has a natural zero point, e.g., the centigrade temperature scale.

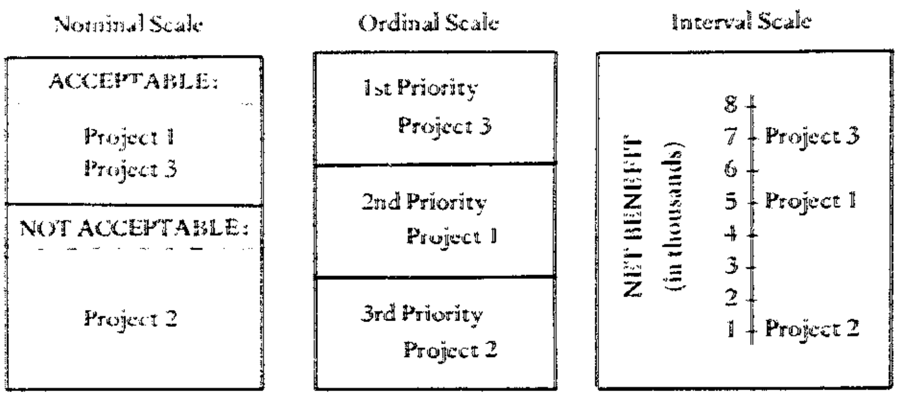
SHORT DESCRIPTION

Rating scales are described by their uses:

1) To rank the preferences for a set of factors: *ordinal* and *interval* scales.

2) To classify or categorize a dissimilar set of factors: *nominal* scales.

FIGURE 1
Examples of Rating Scales Applied to Discrimination Among Three Projects



3) To indicate the degree one factor exceeds another on a specified basis of comparison: *interval* and *ratio* scales.

The scale selected determines how discriminating the rater can be.

ADVANTAGES

Rating scales allow a quantitative comparison. If the comparison involves several factors, the discrimination between factors is enhanced by relating it to a physical dimension (the position or interval on ratio scales).

Factors quantified on rating scales may be combined to reflect a quantitative assessment of cumulative effect, e.g., the pooled judgments of a group of raters.

LIMITATIONS

Rating scales are constructed by subjective judgments in the assignment of rank or interval on the scale. This fact is sometimes lost when the rating is transferred to other tasks or used as information in other tasks.

REQUIRED RESOURCES

LEVEL OF EFFORT

The major task is to assign the rating for each factor. This may be an involved or a straightforward process, depending on the ultimate use of the rating. For example, rating may be used directly as part of cost-benefit analysis (CBA, page 212) or as an aggregated form to reflect multiple dimensions of discrimination (MCU, page 32). The aggregation process tends to minimize the contribution of any one rating.

SKILL LEVEL

Expertise is required in selecting the appropriate kind of rating scale and its parameters. The rating process is subjective and may combine the individual judgments of experts or project clients (see Delphi, DLP, page 168).

TIME REQUIRED

Nominal scales usually require little time since only classification is involved. Ordinal scales can be constructed quickly, particularly if only a few factors are to be ranked. Interval and ratio scales may require more time to construct and establish ratings because more judgment is involved.

DESCRIPTION OF TOOL

REQUIRED INPUTS

The inputs required are simply the scale selected for the ratings (nominal, ordinal, etc.) and the set of factors to be rated. If the rating is to be conducted by someone other than the person who constructed the scale, a sample rating is useful to illustrate the process. The dimension on which the comparisons and contrasts are to be made must be clearly identified and understood.

TOOL OUTPUT

The output is a rating scale which quantifies the subjective assessment of the factors.

IMPORTANT ASSUMPTIONS

The construction and application of rating scales rest on the assumption that humans can discriminate along the rating dimension. There are two limiting factors involved: comparative and absolute judgment. The first suggests that humans are limited in their ability to discriminate between two adjacent factors along dimensions such as color, tone, volume, smell, size, length, etc. The second suggests that the number of discrete intervals which may be recognized along any one dimension is limited. For example, we recognize only four different tastes: sweet, sour, salt, and bitter. Discrimination is based on a combination of taste, texture, smell, and appearance. The implication is that it would be unproductive (and misleading) to ask the rater to distinguish more intervals than he is psycho-physiologically able to (Garner, 1960).

METHOD OF USE

GENERAL PROCEDURE

1. Determine the attributes or factors to be rated.
2. Determine the best scale for rating the factor.
   2.1 Consider the degree of subjective judgment that is feasible.
   2.3 Determine the time available and the discrimination desired.
3. Construct the rating scale.
4. Rate the attributes or factors.
5. Verify the consistency of the ratings.

EXAMPLES

Nominal Scale

Any classification system represents a nominal scaling of variables. For example, the tools in this handbook are categorized nominally by their major purpose. In general, the nominal classification of items is possible only if the categories are mutually exclusive and exhaustive. The latter requirement is usually met by a catch-all category, e.g., "none of the above."

Ordinal Scale

There are several examples of the construction and application of ordinal scales in this handbook, e.g., the *rank-ordering* method described in Nominal Group Techniques (see NGT, page 14).

Interval and Ratio Scales

Interval scales are used in assessing utility functions (see Multiple-Criteria Utility Assessment, MCU, page 32). Subjective Probability Assessment (SPA, page 137) requires an interval scale to rate the likelihood of events occurring. Krueckeberg (1974) describes the use of rating scales in urban planning.

THEORY

Rating scales are based on the theory of psychophysical measurement (Garner, 1960). The literature of psychology, sociology, and decision making abounds with empirical studies on the subject.

Two works are of particular interest: Kaufman (1976) describes rating scales in a treatment of a systems approach to identifying and solving problems. Kneppreth, et al. (1972) catalog a number of different worth assessment techniques. Other studies (Huber, et al., 1969) deal with the issues of the aggregating group judgments. The results are significant, particularly where priorities are to be ranked in such a way that second and third choices are included.

BIBLIOGRAPHY

Garner, W. R. "Rating Scales, Discriminability, and Information Transmission." *The Psychological Review* 67 (November 1960): 343-52.

Huber, G.; Sahney, V.; and Ford, D. "A Study of Subjective Evaluation Models." *Behavioral Science* (November, 1969).

Kaufman, Roger. *Identifying and Solving Problems: A Systems Approach.* La Jolla, Calif.: University Associates, 1976.

Kneppreth, N. P.; Gustafson, D. G.; and Leifer, R. P. *The Assessment of Worth: Techniques.* Madison: Department of Industrial Engineering, University of Wisconsin, 1972.

Krueckeberg, Donald, et al. *Urban Planning Analysis.* New York: John Wiley and Sons, 1974.

Miller, G. A. "The Magic Number Seven ± Two." *Journal of Experimental Psychology.*

Multiple Criteria Utility Assessment

PREREQUISITE TOOLS

None.

USAGE

PURPOSE

Multiple criteria utility assessment is a systematic procedure for assessing the worth of complex alternatives.

USES

Utility assessment provides a common scale for combining judgments on more than one dimension. The technique is used to:

1) Evaluate alternatives using more than one criterion.

2) Combine effectiveness measures into a single aggregated utility, e.g., as in cost-effectiveness analysis (CEA, page 219).

3) Determine a common criterion for valuing the possible outcomes in a decision under risk (see Decision Trees, DTR, page 141).

4) Provide a common measure for comparing the performance of alternative plans (e.g., Contingency Analysis, CGA, page 147).

KEY DEFINITIONS

1) *Utility* is a quantitative expression of the worth or satisfaction associated with an outcome.

2) A *utility function* associates the possible levels a criterion may take with the utilities for those levels.

3) A *utility matrix* presents the elements of a decision under certainty: alternatives, criteria for evaluating the alternatives, weights indicating the relative importance of the criteria, and the assessed utilities (see figure 1).

FIGURE 1

Utility Matrix for Evaluating Alternatives

CRITERIA	WEIGHT	ALTERNATIVES A	ALTERNATIVES B
x_1	w_1	U_{A1}	U_{B1}
x_2	w_2	U_{A2}	U_{B2}
x_3	w_3	U_{A3}	U_{B3}
Total Weighted Utility		U_A	U_B

SHORT DESCRIPTION

In order to compare and evaluate various alternatives (A, B, . . .), several criteria (x_1, x_2, . . .) are first specified (see figure 1). The decision maker considers each criterion separately, assessing the relative *utility* for different criterion levels. The criteria are weighted to represent their relative importance to the decision maker. The aggregate utility for each alternative is determined by computing the weighted sum of the individual utilities for each criterion. Alternatives are compared on the basis of overall utilities.

ADVANTAGES

Valuing alternatives using measures like expected payoff or costs ignores the preferences the decision maker may have for incremental benefits or costs. Utility assessments transform these preferences into quantitative scales which can be combined to determine aggregate utility.

Where a complex alternative must be evaluated, this technique requires the decision maker to consider only one criterion at a time. This simplifies the assessment task and increases the consistency of subjective judgments.

LIMITATIONS

Not all qualitative criteria can be assessed quantitatively, e.g., political acceptability. Multiple criteria utility assessment makes no allowance for preferences which change over time.

REQUIRED RESOURCES

LEVEL OF EFFORT

Multiple criteria utility assessment requires the cooperation of the analyst and the decision maker. The analyst frames the decision situation by identifying alternatives and working with the decision maker to specify criteria for evaluating the alternatives. The decision maker quantifies his preferences in the form of a utility function for each criterion. Aggregating utilities is then a straightforward analytical task.

SKILL LEVEL

Effective communication between analyst and decision maker is essential for eliciting utility functions and weighting criteria. The analyst must be able to evaluate the degree to which each alternative meets the criterion in question, a process which can involve subjective judgment.

TIME REQUIRED

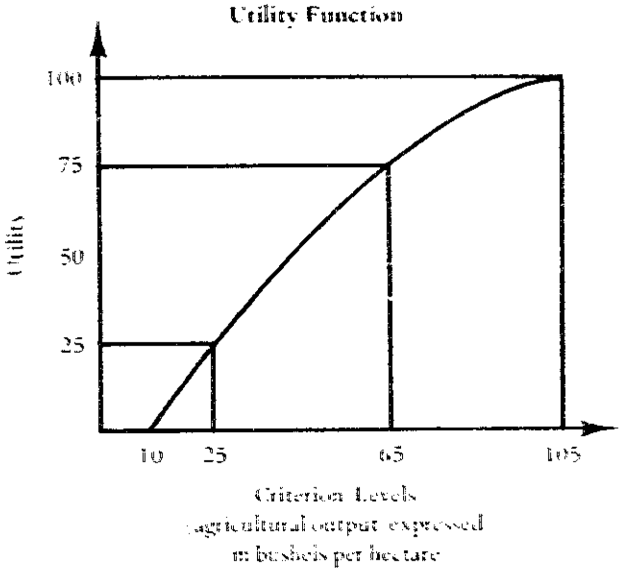
Determining utility functions and checking for consistency can take half a day. Otherwise, the computations and evaluations are not time-consuming, provided necessary information is available.

DESCRIPTION OF TOOL

REQUIRED INPUTS

The criteria by which the alternatives are judged must be specified. The criteria may be derived from an analysis of objectives (Objective Trees, OBT, page 49) or from the nature of the decision situation. The alternatives must be sufficiently detailed so that the decision maker can judge the extent to which each meets the criteria.

FIGURE 2
Utility Function



TOOL OUTPUT

The first products of the multiple criteria utility assessment technique are the utility functions corresponding to each criterion (see figure 2). These transfer the criterion levels to utilities (e.g., the utility of 65 bushels per hectare is 75*). Utility functions can be analyzed to indicate the underlying preferences of the decision makers, e.g., a preference to avoid risk (see Bierman, et al., 1973).

In a decision situation, the ultimate result is a quantitative ranking of the alternatives by decreasing aggregate utility. This measure can be used in other techniques where alternatives are evaluated using multiple criteria (e.g., Cost-Effectiveness Analysis, CEA, page 219).

IMPORTANT ASSUMPTIONS

Utility is a measure of satisfaction with an outcome and has the property of additivity. Utilities assessed for more than one criterion may be added to indicate a preference based on complex multi-dimensional judgments (see Rating Scales, RTS, page 29).

The criteria applicable to a decision are fixed dimensions for assessing the degree to which an alternative possesses each of the attributes, e.g., the dimensions do not vary from alternative to alternative in the decision situation although the criterion level for each alternative varies. That is, subjective preferences are consistently applied to all alternatives in the decision situation.

*Utilities are dimensionless, but may be thought of as percentage relative to complete satisfaction (100%) with a criterion level.

METHOD OF USE

GENERAL PROCEDURE

1. **Identify the decision criteria used to assess each alternative.**
   1.1 Determine nominal scale categories for the qualitative criteria (see Rating Scales, RTS, page 29).
   1.2 Determine the practical limits for quantifiable criteria, e.g., yield per hectare may range from 10 to 105 bushels.

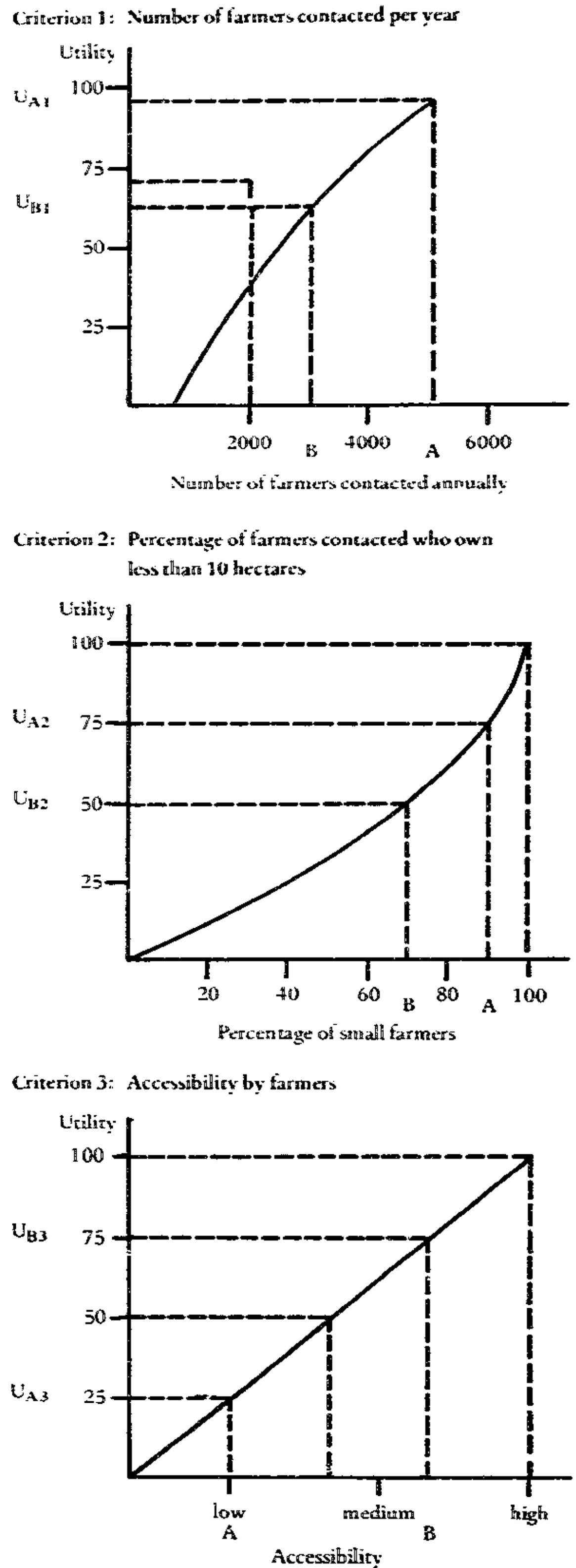
2. Construct a utility function for each qualitative criterion.
   2.1 Identify a most preferred and a least preferred level.
   2.2 Assign utilities of 100% and 0% satisfaction.
   2.3 Assess the utilities for intermediate levels of the criterion.

3. Construct utility functions for each quantitative criterion.
   3.1 Assign 100% utility to the quantitative criterion level, just beyond the practical limit which is most preferred.
   3.2 Assign 0% utility to the criterion level at the other extreme of the practical range of values.
   3.3 Assess the utility value which indicates the percentage satisfaction with intermediate criterion levels, e.g., "if your satisfaction with a harvest of 105 bushels is 100%, then what is your satisfaction with 60 bushels per hectare?"
   3.4 Connect a curved line through the intermediate utility values (see figure 2).

4. Test the internal consistency of the utility assessments.
   4.1 Pose questions like: "You have said that you would be 25% satisfied with 35 bushels and 75% satisfied with 60 bushels. Are 60 bushels actually preferred three times as much as 35 bushels?"
   4.2 If the answer is no, then adjust one or both utility assessments.

5. **Considering one criterion at a time, determine the utility for each alternative.**
   5.1 Construct the utility matrix (figure 1).
   5.2 Using the utility function for the respective criterion, evaluate the utilities for the various alternatives by assessing the criterion level achieved by each and then using the utility function to read off the corresponding utility.
   5.3 Enter these percentages in the rows corresponding to that criterion of the utility matrix.

FIGURE 3
Utility Functions for Evaluating Farmer Contact Strategies



6. **Weight the criteria.**
   6.1 Ask the decision maker to order the criteria by increasing importance to the decision.
   6.2 Assign a weight of 1.0 to the most important criteria.
   6.3 Ask the decision maker to indicate the fraction corresponding to each remaining criteria, e.g., "is this criterion one-half or one-third as important as the most important criterion?"

7. **Compute the aggregated utilities.**
   7.1 Multiply each utility by the weight assigned to the respective criterion for that row of the matrix.
   7.2 Compute the aggregated utility for an alternative by summing the weighted utilities across all criteria. Referring to figure 1, for alternative A:

   Aggregate utility of A = $w_1 U_{A1} + \ldots + w_n U_{An}$

   where

   U_{An} = utility of alternative A for criterion n

   w_n = weight of n^{th} criterion (a positive fraction less than 1)

   7.3 Rank-order the alternatives by descending values of their aggregated utility. The alternative giving the greatest satisfaction is the one having the greatest aggregated utility.

EXAMPLE

The Temasek Ministry of Agriculture was considering two alternatives for disseminating innovations to small farmers: A) establishing farmer training centers at strategic locations in the region, or B) strengthening and expanding the agricultural extension service. The effectiveness of the alternatives were evaluated using three criteria: 1) the number of farmers contacted per year; 2) the percentage of farmers contacted having holdings of 10 hectares or less; and 3) the accessibility of the approach. Criterion (3) was formulated as a qualitative assessment of the ease with which farmers could use the system.

Utility functions were derived for the three criteria (see figure 3). The Ministry of Agriculture decision makers placed a high utility on reaching a significant percentage of small farmers. Also, no utility was associated with reaching less than 500 farmers as this was the present level of contact for the existing extension program. The practical limit for criterion (1) was the total number of farmers in the region, estimated at 10,000.

A utility matrix was constructed, and the utilities of the alternatives were evaluated (see figure 4). Considering criterion (2), the mobile extension workers could be more selective in contacting farmers, while only the larger farmers would tend to use the training center services.

FIGURE 4
Utility Matrix for Ministry of Agriculture Farmer Contact Strategy

Criteria W	Weights	Alternatives: A) Training Centers	Alternatives: B) Strengthened Extension
1. Total farmers contacted	1.0	90	60
2. Percentage small farmers	0.5	75	50
3. Accessibility	0.5	25	75
Weighted total		140	122.5 = 123

The importance of each criterion was evaluated and weights were assigned (see figure 4). The total number of farmers reached was judged to be twice as important as the other decision criteria. The weighted aggregate utility for each utility was computed. For example:

$$\text{Aggregate utility for alternative A} = (1.0)(90) + (0.5)(75) = (0.5)(25) = 140$$

The weighted aggregate utility for alternative B was computed at 123. Consequently, the farmer training center strategy was preferred. The aggregated utilities were then compared to projected costs (see Cost-Effectiveness Analysis, CEA, page 219).

THEORY

Huber (1974) identifies two methods by which multiple criteria utility assessment is carried out. The method shown here has been the client-explicated model, since the client (decision maker) indicates his utility for various levels of each criterion. In the observer-derived model, the client is asked to make a global judgment of the overall utility associated with a set of criterion levels. The client estimates the utility for several such sets; regression analysis (see Regression Forecasting, RGF, page 160) is used to estimate the utilities associated with each criterion.

BIBLIOGRAPHY

Bierman, Harold, Jr.; Bonini, Charles P.; and Hausman, Warren H. *Quantitative Analysis for Business Decisions*. Homewood, Ill.: Richard D. Irwin, 1973.

Huber, George P. "Methods for Quantifying Subjective Probabilities and Multi-Attribute Utilities." *Decision Sciences* 5 (July 1974): 430-58.

Surveys

PREREQUISITE TOOLS

Questionnaires, QTN, page 19.

USAGE

PURPOSE

A sample survey is used to gather information from a fraction of a subject population in order to identify and measure its attributes.

USES

A sample survey can be used to:

1) Explore the issues, opinions, and attitudes of inhabitants of a region or a selected target population.

2) Test fundamental hypotheses and assumptions which have been developed by a pilot study or other experiment.

3) Provide feedback on the progress of a project by measuring the delivery of services.

4) Form the basis for a post facto evaluation of the overall effectiveness of a project by measuring its impact on recipients and non-recipients.

5) Quantify statistical data used in the cost-benefit analysis (CBA, page 212) and cost-effectiveness analysis (CEA, page 219) of proposed projects.

KEY DEFINITIONS

1) A *subject population* is the set of all events or entities which possess certain specified characteristics, e.g., all married couples in a region of the country of Temasek.

2) A *sample* is a subset selected from a subject population, the attributes of which are assumed to hold true for the total population.

3) A *measuring instrument* is a technique for eliciting and measuring responses from a subject.

4) A *census* is a survey of all members of a subject population.

5) *Participant observation* is the gathering of information about and impressions of a selected group by direct interaction over an extended period of time, e.g., a social scientist living in a village to interact and observe behavior patterns, social relationships, and economic structures.

SHORT DESCRIPTION

A sample survey is a means of gathering maximum information at minimum cost. A *sample* of the *subject population* is selected based on the purpose of the survey and time and cost limitations. Two common *measuring instruments* are used to gather information: interviews (IVW, page 23) and questionnaires (QTN, page 19). They may be used together and administered by trained personnel.

Survey results are tabulated and analyzed in order to assess characteristics of the subject population. Surveys are used in evaluation research for the "assessment of the process and/or consequences of deliberate and planned interventions" (Warwick and Lininger, 1975, page 51). Using rating scales (RTS, page 29) and statistics (see Histograms, HIS, page 131), the analyst makes inferences about the need for, the progress of, and the impact of development projects. These inferences are tested using the sample survey results.

ADVANTAGES

1) Information about a population may be gathered from a fraction of the population. This minimizes expensive data gathering costs.

2) A great deal of information can be gathered by making a careful selection of a representative sample.

3) In contrast to *participant observation*, a carefully designed survey permits generalization about the characteristics of the population as a whole.

4) Because fewer interviewers are required than for a *census*, the training and control over them is usually better.

LIMITATIONS

Even a small survey may be prohibitively expensive, particularly if accessibility to the subject population and training personnel are factors.

Biases in the information gathered and the sampling procedure may lead to erroneous inferences.

The return for mailed questionnaires is typically very low and may jeopardize the validity of the results. However, personal interviews introduce an additional source of bias (see Interviews, IVW, page 23).

A sample survey is less useful than participant observation when the analyst knows little about the society under study.

REQUIRED RESOURCES

LEVEL OF EFFORT

Surveys are normally major undertakings. The decision maker will have to weight the costs against the benefits (see Cost-Benefit Analysis, CBA, page 212) before undertaking the survey. The analyst will expend the major effort in designing the survey and analyzing the responses. If interviewing is desirable, the selection, training, and supervision of interviewers is crucial.

SKILL LEVEL

Survey design requires a good deal of research knowledge and statistical sophistication. Skills in selecting representative samples, constructing questionnaires, and analyzing data are essential.

TIME REQUIRED

A sample survey can be a very time-consuming process, not only in actually conducting the survey but in the planning and analysis stages. A critical path schedule is presented as an example in Gantt Charts (GNT, page 252) for a 33-day task.

SPECIAL REQUIREMENTS

A variety of statistical packages are available on computer programs. However, to use them to analyze sample survey results, the data must be coded in compatible formats (see Questionnaires, QTN, page 19). Though not strictly necessary, computerized techniques have the great advantage of shortening the time required to analyze results and permitting complex statistical measures to be derived from the data.

DESCRIPTION OF TOOL

SUPPLEMENTAL DEFINITIONS

1) A *simple random sample* is made so that every member of the target population has an equal probability of selection.

2) A *stratified sample* selects a proportional sample at random from each of the groups in a stratification of the total population, e.g., the sample includes an equal number of randomly selected individuals from low, middle, and high income strata.

3) *Cluster sampling* is the process of randomly selecting several clusters of subgroups from the total population and surveying all members of the selected subgroups, e.g., only three villages are selected in the region of the subject population, but every inhabitant of the village is interviewed.

4) *Multi-stage sampling* draws random samples in stages. The first stage selects random groups within the target population. A second stage randomly selects subgroups (or individuals) from within the groups, and so on.

REQUIRED INPUTS

The problem definition, the desired subject population, the measuring instruments, and the sample size are necessary inputs for a survey. The decision maker has to interact with the analyst to determine the sample size. The size will affect costs as well as reliability. A choice between potential measuring instruments is made depending on the type of problem being faced. the costs of using the instrument. and the expected time lag before arriving at a final analysis.

TOOL OUTPUT

The tabulation of the responses is of primary interest to the decision maker. The simplest type of output would be marginal tabulations. indicating how the population is distributed across a list of categories. For example:

Religion	Percentage of Population
Protestant	15%
Catholic	5%
Muslim	30%
Buddhist	40%
Other	10%
TOTAL	100%

Hence. Muslims would form 30% of the subject population (see Histograms. HIS. page 131).

Another output is "correlation analysis." This analysis shows how variables are related to each other. For example:

	Response on Birth Control		
	Opposed	Indifferent	Agree
Protestant	5%	5%	90%
Catholic	60%	30%	10%
Muslim	55%	10%	35%
Buddhist	10%	10%	80%
Other	2%	15%	83%

This output would indicate that Catholics and Muslims generally oppose birth control. Hence. the decision maker may have to consider strategies to establish linkages with Catholic and Muslim priests if birth control is to be implemented (see Regression Forecasting, RGF, page 160).

A final type of output is due to "longitudinal research," where the attributes of a population are measured at two or more points in time. The results are used to indicate changes in measured attributes which are caused by planned interventions. For example, the effectiveness of a birth control education program would be assessed by repeating the survey of attitudes at several intervals after the program had started.

IMPORTANT ASSUMPTIONS

A sample population can be randomly selected to be representative of the subject population. Measuring instruments are unbiased. The inferences from the sample results to the target population are statistically valid.

METHOD OF USE

GENERAL PROCEDURE

Since sample surveys vary greatly in purpose, design. and execution. below is a broad sketch of the steps involved (for a more detailed description. see. for example. Warwick and Lininger. 1975).

1. **Specify the purpose of the survey and its uses.**

2. **Identify the subject population.**
   - 2.1 Consider the kinds of inferences which are to be made.
   - 2.2 Consider the accessibility and cooperativeness of the subject population (they may have already been saturated by surveys or experiments).

3. **Select a sample method:**
   - a) Simple random sampling.
   - b) Stratified sampling.
   - c) Cluster sampling, or
   - d) Multi-stage sampling.

4. **Determine the best sampling size.**
   - 4.1 Consider the desired accuracy and reliability of the survey results: the larger the sample, the more reliable the inferences about the target population.*
   - 4.2 Consider the cost of gathering data: the larger the sample, the more time or personnel required.
   - 4.3 Consider the cost of processing the data: unless the results are processed automatically, the smaller the sample, the less the cost in both time and effort.
   - 4.4 Consider the desired discrimination** in target population: the more homogeneous the target population, the smaller the sample may be.

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*Statistical reliability is proportional to the absolute sample size, not the fraction of the target population.

**This is related to the sampling method selected and the consideration in 4.1. Statistical reliability of quantitative attributes can be determined analytically (see Warwick and Lininger, 1975).

5. Specify the measuring instrument and train personnel.
    5.1 If a questionnaire is used, determine how it will be administered (see Questionnaires, QTN, page 19).
    5.2 If direct interviews are used, select and train the interviewers, taking into account cultural compatibility with the target population.

6. Design the survey questionnaire and pretest (see Questionnaires, QTN, page 19).
    6.1 Determine if both open-ended and close-ended questions are necessary. The former will require more training and interpretive analysis of results.
    6.2 Correct any deficiencies in design by pretesting on a small sample of the target population. If this is not desirable, then pretest on a group which matches communication characteristics of the target population, e.g., literacy level, candor, cooperativeness.

7. Conduct the survey.
    7.1 Arrange necessary transportation.
    7.2 Monitor interviewers by spot-checking survey results.
    7.3 Start analyzing results immediately in case adjustments to the questionnaire or the interviewing procedure are necessary.

8. Tabulate and analyze results.
    8.1 Prepare histograms for quantitative measures and compute descriptive statistics (see Histograms, HIS, page 131).
    8.2 Interpret and summarize open-ended responses (see Delphi, DLP, page 168).
    8.3 Analyze results to test statistical inferences.

9. Report conclusions.
    9.1 Include questionnaire and sampling procedure as appendices.
    9.2 In addition to presenting data and summary statistics, reflect on implications of the results.

EXAMPLES

The examples of sample surveys cross many fields and address a variety of purposes. Glock (1967) provides examples of how surveys have been used in sociology, economics, social work, and education.

The Survey Research Unit (Illo and Lynch, 1975) has been extensively involved in data gathering for the Bicol River Integrated Development Program in the Phillipines. The issues addressed range from social indicators such as "The Quality of Life" to yield data on rice production.

Mann (1974) describes a comprehensive survey conducted in Africa to identify the problems of small farmers.

THEORY

Survey research has developed into a theoretical area in its own right (Festinger and Katz, 1953, and Warwick and Lininger, 1975). Effective use of measuring instruments are described in Young (1956) and Cicourel (1964).

The underlying theory upon which sample surveys are based is the process of statistical inference and hypotheses testing. Meyers and Grossen (1974) describe basic statistical methods, and Smith (1975) gives a useful treatment of these methods in relation to sample surveys designed to gather quantitative project data. Kearl (1976) presents a collection of experiences, rules-of-thumb, and common sense in the design and execution of sample surveys.

BIBLIOGRAPHY

Cicourel, Aaron V. *Methods and Measurement in Sociology*. New York: The Free Press, 1964.

Festinger, L., and Katz, D. *Research Methods in the Behavioral Sciences*. New York: Holt, Rinehart and Winston, 1953.

Glock, Charles Y., ed. *Survey Research in the Social Sciences*. New York: Russell Sage Foundation, 1967.

Illo, Jeanne Frances, and Lynch, Frank. "Patterns of Income Distribution and Household Spending in the Bicol River Basin." Social Survey Research Unit Research Report Series, No. 13. Bicol River Basin Development Program, Naga City, Phillipines, 1975.

Kearl, Bryant, ed. *Field Data Collection in the Social Sciences: Experiences in Africa and the Middle East*. New York: Agricultural Development Council, 1976.

Kerlinger, Fred N. *Foundations of Behavioral Research*. New York: Holt, Rinehart and Winston, 1964.

Mann, R.D. *Rural Africa Development Project: Identifying the Problems of Small Farmers*. London: Intermediate Technology Publications, 1974.

Meyers, Lawrence S., and Grossen, Neal E. *Behavioral Research: Theory, Procedure, and Design*. San Francisco, Calif.: W.H. Freeman, 1974.

Smith, Ken F. *Statistical Survey and Analysis Handbook*. Manila, Phillipines: United States Agency for International Development, March 1975.

Warwick, Donald P., and Lininger, Charles A. *The Sample Survey: Theory and Practice*. New York: McGraw-Hill, 1975.

Young, Pauline V. *Scientific Social Surveys and Research*. Englewood Cliffs, N.J.: Prentice-Hall, 1956.

Organizational Climate Analysis

PREREQUISITE TOOLS

None.

USAGE

PURPOSE

Organizational Climate Analysis determines the *organizational climate* required to achieve desired behavior from a *target group* within an organization.

USES

Climate analysis may be used to:

1) Identify *organizational attributes* (climate) which affect behavior.

2) Compare the climates of similar organizations, e.g., secondary schools within a country, or divisions within an army.

KEY DEFINITIONS

1) *Organizational climate* is the relatively enduring quality of the internal environment of an organization that (a) is experienced by its members, (b) influences their behavior, and (c) can be described in terms of the values of a particular set of characteristics (or attributes) (Tagiuri, 1968).

2) A *target group* is a number of individuals with some common roles or characteristics. Examples are students in a school and employees in a government agency.

3) *Organizational attributes* include the elements or components of an organizational system and the interrelationships among them.

4) *Measuring instruments* are techniques for eliciting and measuring responses from a subject. Examples are questionnaires (QTN, page 19) and interviews (IVW, page 23).

SHORT DESCRIPTION

A set of measurable organizational attributes which can be used as criteria for describing an organization's climate is determined. *Measuring instruments,* which engage people within the organization, are then utilized to determine the desired values of these attributes and thus the desired organizational climate. The present organizational climate is then determined through observing and objectively measuring the behavior or performance of the target group. Analysis of the climate and behavior then leads to a proposed organizational climate which can encourage desired behavior.

ADVANTAGES

Quantitative measures of organizational attributes are identified which help to determine the achievement of the desired organizational climate.

LIMITATIONS

1) If the people within an organization are unable to express their perceptions about the organizational attributes, then adequate measurements cannot be obtained.

2) The analysis requires an external consultant whose services may be expensive.

3) If the cooperation of the target group is not forthcoming, the results of the climate analysis may be invalid or unacceptable to the target group.

REQUIRED RESOURCES

LEVEL OF EFFORT

The analyst will expend considerable effort helping the decision maker to identify the desired types of behavior and the organizational attributes of the climate: to provide measures for these attributes, to construct measuring instruments (and possibly administering them), and to analyze the results obtained.

SKILL LEVEL

The analyst should have a strong background in organizational theory and its related aspects in psychology and sociology.

TIME REQUIRED

The climate analysis is a major effort which takes at least a month. The time required varies with the size of the target group, the number of organizations, and the accuracy desired.

DESCRIPTION OF TOOL

REQUIRED INPUTS

Perceptions about the organizational climate are solicited not only from the target group, but from other individuals within the organization.

Behavior may be judged by several criteria, including routine job performance, creativity, and scholastic ability. These are operationalized into measurable criteria, such as number of cars assembled per hour, number of ideas generated, and grade point average, respectively. Objective Trees (OBT, page 49) may be a useful technique for determining these criteria.

Sells (1968) identifies eight criteria to be considered in climate assessment (see figure 1).

FIGURE 1
Dimensions to Be Considered in Climate Assessment

1. **Objective and Goals**
   a. Remoteness of goals
   b. Formal vs. informal mode of designation
   c. Unitary vs. multiple goals
2. **Philosophy and Value Systems**
   a. Dominant economic values with respect to issues of property, profit, taxation, etc.
   b. Status and value accorded the individual, minorities, dependent individuals, and groups
3. **Personnel Composition**
   a. Intellectual potential
   b. Physical traits
   c. Position in status hierarchy
4. **Organization**
   a. Size
   b. Differentiation
   c. Autonomy
5. **Technology**
   a. Products and services involved
   b. Types and degree of technological complexity
6. **Physical Environment**
   a. Social isolation
   b. Types of furnishings
7. **Social-Cultural Environment**
   a. Language
   b. Living standards and routines
   c. Recreation
8. **Temporal Characteristics**
   a. Duration of individual participation
   b. Extent of daily participation

TOOL OUTPUT

The analyst will tell the organizational decision maker(s) which organizational attributes are aiding and which are hindering achievement of the desired behavior. Discussion between the analyst and the decision maker will then determine the changes to be made in the organizational climate.

METHOD OF USE

GENERAL PROCEDURE

This procedure may be followed in a climate analysis. Note that these steps are meant to provide only a general understanding.

1. Determine the basis for a climate analysis.
   1.1 Identify the target group (in consultation with the decision maker).
   1.2 Define desired behavior from the target group.
   1.3 If comparison of organizations is to be done, determine the number to be included in the study.

2. Obtain operational definitions of climate and behavior.
   2.1 Identify one or more measurable attributes for the organizational climate. The attributes may be comprehensive or they may be selectively perceived.
   2.2 Define objective criteria for measuring behavior.

3. Measure climate and behavior.
   3.1 Identify individuals in the target groups
   3.2 Construct a measuring instrument for discovering individual perceptions (see Rating Scales, RTS, page 29, and Questionnaires, QTN, page 19).
   3.3 Administer the measuring instrument (see Interviews, IVW, page 23).
   3.4 Obtain objective measures of individual behavior by observation and from past records.

4. Analyze results.
   4.1 Analyze the responses to determine the perceptions of the organizational climate.
   4.2 Aggregate the responses for each organization to provide a measure of climate for the organization.
   4.3 Compare the measured attributes with the measures of behavior to determine which attributes significantly affect behavior (see Regression Forecasting, RGF, page 160).

5. Propose the desired organizational climate.
   5.1 Identify those attributes which seem to significantly affect the desired behavior.
   5.2 Propose an organizational climate which may achieve the desired behavior.

EXAMPLES

Shukla (1974) interviewed 25 people (faculty, students, staff) in a university department to assess the organizational climate. This climate analysis was intended to serve as a basis for: 1) changing policies in the department by the top management, 2) identifying teaching needs of the faculty, and 3) changing organizational attributes and practices. Some of the organizational attributes identified were decentralized decision making, interpersonal relationships, cohesiveness, rewards from teaching, faculty workload distribution (research, teaching, and advising), flexibility in choice of courses for students, student and faculty perceptions of independent study, departmental goals, and admission requirements.

Pace (1968) synthesized the results of several climate analyses related to the measurement of college environments. Dimensions of the college climate were scholarship (e.g., intellectual orientation of students), awareness (e.g., self-expression), practicality (e.g., vocational student culture), bureaucracy (e.g., faculty affiliation), and propriety (e.g., social conformity). These dimensions and their attributes were then related to some measure of behavior, e.g., high productivity of scholars, research work.

THEORY

The analysis of organizations encompasses a variety of disciplines including political science, social psychology, sociology, public administration, micro-economics, business and management science, and industrial engineering. The analytical bias depends largely upon the function of the organization.

Organizational Climate Analysis focuses on identifying the attributes which will enable a diagnosis of problems in the organizational environment, and assessing qualitative factors with which to measure improvement. The focus is largely on interpersonal factors and the orientation is social-psychological.

BIBLIOGRAPHY

Pace, C. Robert. "The Measurement of College Environments." In *Organizational Climate: Explorations of a Concept*, edited by Renato Tagiuri and George H. Litwin. Boston, Mass.: Graduate School of Business Administration, Harvard University, 1968.

Sells, S. B. "An Approach to the Nature of Organizational Climate." In *Organizational Climate: Explorations of a Concept*, edited by Renato Tagiuri and George H. Litwin. Boston, Mass.: Graduate School of Business Administration, Harvard University, 1968.

Shukla, Ramesh. "Report to the Graduate Task Force on Department Climate Analysis." Department of Industrial Engineering, University of Wisconsin, 1974.

Tagiuri, Renato. "The Concept of Organizational Climate." In *Organizational Climate: Explorations of a Concept*, edited by Renato Tagiuri and George H. Litwin. Boston, Mass.: Graduate School of Business Administration, Harvard University, 1968.

Tagiuri, Renato, and Litwin, George H., eds. *Organizational Climate: Explorations of a Concept*. Boston, Mass.: Graduate School of Business Administration, Harvard University, 1968.

III
Defining Objectives

Function Expansion
Objective Trees
Intent Structures

Defining project objectives is a universal imperative of a systems approach. Objectives are often unspecified, ill-defined, nonconsensual, and/or time-varying. Three techniques were selected which address these characteristics. Two techniques focus on structuring objectives in a hierarchy (Objective Trees and Intent Structures). A third tool derives from systems engineering and represents a hierarchical view of system function (Function Expansion). All three assume that defining objectives is a realizable task.

Function Expansion

PREREQUISITE TOOLS

None.

USAGE

PURPOSE

Function expansion identifies the *function* of a *system* and relates it to a *function hierarchy.*

USES

Function expansion can be used to:

1) Generate a hierarchy of functions.

2) Select a necessary function in the hierarchy for which a system is to be designed.

3) Communicate and facilitate understanding of the system's function in a hierarchy of systems.

4) Create cohesiveness among group members in moving toward a common function and related project *goals.*

5) Provide input to other tools, e.g., IDEALS Strategy (IDL, page 231).

KEY DEFINITIONS

1) The *function* is the primary concern of a system, e.g., the mission of a project.

2) A *system* is a collection of components which interact to achieve a common function.

3) *Function hierarchy* is an ordering of system functions from the most specific to the broadest function (see figure 1).

4) The *goal* of a project is a value judgment which satisfies one or more needs. It measures the effectiveness of achieving a function. For this tool, a goal is typically to minimize costs, maximize profits, or reduce overtime.

SHORT DESCRIPTION

A function expansion is a list of transitive action verbs which describe the functions of systems. A function expansion excludes terms such as "make a profit" or "minimize costs," since these are goals or desired measures of effectiveness for achieving a function. The function of a system describes what a system should achieve: the system output describes what form the achievement takes.

A *function hierarchy* is created from the function expansion list. It corresponds to an expanding perspective on the defined scope of a system—each system is part of a larger system, and so on (see figure 1).

ADVANTAGES

1) Efforts to identify problems with the existing system usually make people defensive and uncooperative. By concentrating on the functions of the system being analyzed or designed, all people may be effectively involved.

FIGURE 1

Function Hierarchy for Employment System

Most Unique Specific Function
↑ 1. Provide list of job opportunities
2. Communicate job opportunities to unemployed people
3. Match job specifications with applicant specification
4. Get people and jobs together
5. Find employment for people
6. Fill vacancies in companies and government
7. Have jobs and services carried out
8. Get jobs done
9. Provide services
10. Keep economy functioning
↓ 11. Promote general welfare
Most General Function

2) Attention to functions, rather than goals, facilitates alternative idea generation because a goal (as defined above) imples an evaluation criteria. Evaluation must be deferred when generating ideas (see Brainstorming, BSG, page 3).

3) Creativity in developing solutions is encouraged by knowing all the levels in the hierarchy of functions. The decision maker can focus on system function rather than on describing unnecessary current activities.

LIMITATIONS

1) Identifying the real functions of a system may be no easier than identifying problems. It requires insight and knowledge about the system.

2) Systems are often composed of many subsystems, each with a variety of functions. Identifying all of them can be taxing. Ordering the function expansion in a hierarchy gives structure or priorities to the functions. There may be no agreement on the final order.

3) Most analysts tend to confuse goals with functions. Specifying a system's goal rather than its function does not really characterize the system's primary concern.

REQUIRED RESOURCES

LEVEL OF EFFORT

A function expansion group exercise must be organized and directed. The Nominal Group Technique (NGT, page 14) is often used to identify functions or purposes, though interacting groups can be used.

SKILL LEVEL

Function expansion group exercises require skill in leadership and experience in group processes. Someone must be able to direct and channel the discussions, avoiding time-consuming digressions about problems and problem identification.

TIME REQUIRED

The time required depends upon:

1) The complexity of the system under study.

2) Previous knowledge of the system or similar systems.

Completing a function expansion typically requires less than a day. In the design process, more time may be required to revise the function hierarchy.

SPECIAL REQUIREMENTS

A group function expansion exercise is facilitated by using a blackboard (or flip chart) and marking pens. Space for posting flip chart pages for easy viewing is desirable.

DESCRIPTION OF TOOL

SUPPLEMENTAL DEFINITIONS

1) A *regularity* is the most frequently occurring (or the most important) condition of several characteristics.

2) *Outputs* are the desired *and* the undesired results of the transformation process of a system. The desired results enable the system to achieve its function.

REQUIRED INPUTS

Developing a function expansion for a system requires:

1) Familiarity with system or source of expressed need.

2) Expertise in leading group processes.

3) Participation of people in the system, users of the system results, experts, and decision makers.

TOOL OUTPUT

A function expansion produces a list of all possible functions of the system, arranged in a hierarchy. This hierarchy can be used as an input to the design of systems using other methods such as the IDEALS Strategy (IDL, page 231).

The hierarchy provides a greater understanding of the system under study and its relation to larger systems, of which the system may be a component.

IMPORTANT ASSUMPTIONS

1) A system is designated as such because it has a function or functions.

2) Every system is part of a larger system.

3) Every system may be divided into subsystems or components.

4) A hierarchy of functions corresponds to the hierarchy of systems (and subsystems).

The System Definition Matrix (SDM, page 67) discusses these assumptions.

METHOD OF USE

GENERAL PROCEDURE

1. Generate function statements by considering desirable outputs.

1.1 Involve concerned people in generating function statements using, for example, a Nominal Group Technique (NGT, page 14). The group should be heterogeneous, involving clients, workers, decision makers, and managers.

1.2 Define a function statement in the form of a transitive action verb and an object. This allows members of the project group to readily visualize a system's action. Typical functions are:

Supply services
Donate manpower
Distribute health supplies

1.3 Avoid verbs which imply the movement of the present condition toward a more desirable state. These are more often end goals or objectives, rather than the purpose or primary concern. Some constructions to avoid are:

Increase profits	Optimize material usage
Decrease expenses	Avoid waste
Make money	Increase machine utilization
Improve productivity	

A function statement is the aim or result "that a system achieves, or is expected to achieve, with no reference to how (who, where, when, etc.) or how well (quantities, qualities) the system operates or is expected to operate" (Johnson, 1975).

1.4 Avoid tying multiple functions together with words like "and" or "in order to."

2. Select the most specific primary function of the system.

2.1 Select the initial specific function from the list of possible functions by using a comparison test. Ask a question like, "Is the function of the system to (function 1) in order to (function 2) or vice-versa?" For example, is the function of the system to "irrigate fields" in order to "regulate water flow," or is the function to "regulate water flow" in order to "irrigate fields"? Clearly "regulate water flow" is a function of the more narrowly defined system. Similarly, to "irrigate fields" is a more specific function of a system to "grow crops."

2.2 Write the selected function at the top of a large sheet of paper or flip chart.

3. Expand the function into a hierarchy.

3.1 Ask the group, "What is the most immediate or direct function of this identified function?" For example, the function of the system to "regulate water" is to "irrigate fields." Ask the same question for irrigating fields.

3.2 Repeat step 3.1 until newly identified functions are beyond the scope of study. The functions are thus arranged in a hierarchy. This process will stimulate the creativity of the group and identify functions that were not on the original list.

4. Select the function level on which planning and design should concentrate.

The recommended solution or system resulting from such efforts should achieve at least this function.

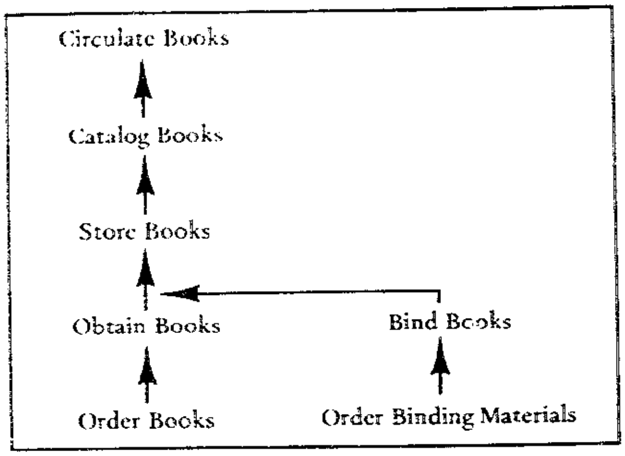
Precautions

1) Do not confuse a goal or end result with a function. "Make a profit" or "decrease poverty" are goals, not functions.

2) Do not branch away from the main function in an attempt to include all possible sub-functions. The function expansion will become too unwieldy. The concept of *regularity* helps avoid this pitfall. If the function expansion is not focussed on the most regular, dominant function in the system, then the expansion may go off on tangential, less important functions.

For example, the function expansion for a library may develop as shown in figure 2. The functions are arranged from the most general to the most specific functions.

FIGURE 2
Forecasting the Function Expansion on the Most Regularly Occurring Concern



3) Do not make big leaps in the function hierarchy. The logical flow from specific to more general functions must be maintained. It is better to be redundant, e.g., rephrasing a function with slightly different words, than to risk being incomplete.

EXAMPLE

A function expansion was to be developed for an employment service system, the initial step in the design of the system. The functions generated in the first step are listed in figure 3. Some were identified as goals rather than functions and were not considered further.

FIGURE 3
Function Expansion List for Employment Service

1) Get people and jobs together
2) Find employment for people
Goal → 3) Reduce unemployment
4) Determine available jobs
5) Determine client job skills
Goal → 6) Increase employment
7) Aid job-seekers
8) Fill vacancies in companies and government
9) Communicate job opportunities to unemployed people
10) Match job specifications with applicant qualifications
11) Provide statistics about unemployment
Goal → 12) Act as a "thermometer" for job needs to advise future careers to students

The most specific function was identified as "to provide list of job opportunities." The function hierarchy was then developed using some of the other functions (see figure 1).

This example is continued in IDEALS Strategy (IDL, page 231).

THEORY

Function expansion is based on the fundamental characteristic of a system: its function (Nadler, 1967). A system is a collection of elements and dimensions which interact to achieve a common function (see System Definition Matrix, SDM, page 67).

Starting with the basic premise that a system is designated as such because it achieves an identifiable function, functions can be identified for a hierarchy of systems. The principle of system hierarchy has two parts:

1) Every system is part of a larger system.
2) Every system can be divided into subsystems or components.

Since each system in a hierarchy of systems has a function, the hierarchy of functions corresponds to the hierarchy of systems. The function hierarchy begins with the most specific primary function and extends to the ultimate, more general function of the largest system of interest (region, state, nation, world, etc.).

Many of these ideas about systems and systems descriptions draw upon the body of knowledge identified as General Systems Theory.

The effectiveness of the group exercise has been supported by empirical research into design strategies (Nutt, 1974).

BIBLIOGRAPHY

Johnston, James. "Class Notes for IE 126." Dept. of Industrial Engineering, University of Wisconsin-Madison, 1975.

Nadler, Gerald. *Work Design.* Homewood, Ill.: R.D. Irwin, 1970.

Nadler, Gerald. *Work Systems Design: The IDEALS Concept.* Homewood, Ill.: R.D. Irwin, 1967.

Nutt, P.C. "Design Methods Research: An Experimental Comparison of the Effectiveness of Planning Procedures." Ph.D. Dissertation, Dept. of Industrial Engineering, University of Wisconsin-Madison, May 1974.

Objective Trees

PREREQUISITE TOOLS

None.

USAGE

PURPOSE

The objective tree technique helps to define project *objectives* and provides a way to order them in a hierarchical structure.

USES

An objective tree is used to:

1) Provide a guiding rationale for systems design and evaluation.

2) Indicate how the attainment of sub-objectives contributes to the accomplishment of higher level objectives.

3) Show how objectives for a project are interrelated.

4) Identify criteria for evaluating alternative means.

5) Help assess the level of impact or scope of a project.

6) Provide necessary inputs to other techniques, such as Logical Framework (LGF, page 260) and Planning, Programming, and Budgeting (PPB, page 236).

KEY DEFINITIONS

1) An *objective* is a specific statement of purpose expressing a desired end. The usual form is:

Infinitive + Object + Qualifying Phrases
(see figure 1)

2) A *tree graph* is a set of linked elements where only one link exists between any two factors (see Tree Diagrams, TRD, page 74). The elements in an objective tree are the objective statements or phrases (see figure 1).

3) *Means-ends analysis* is the identification of alternative actions to achieve specified ends.

SHORT DESCRIPTION

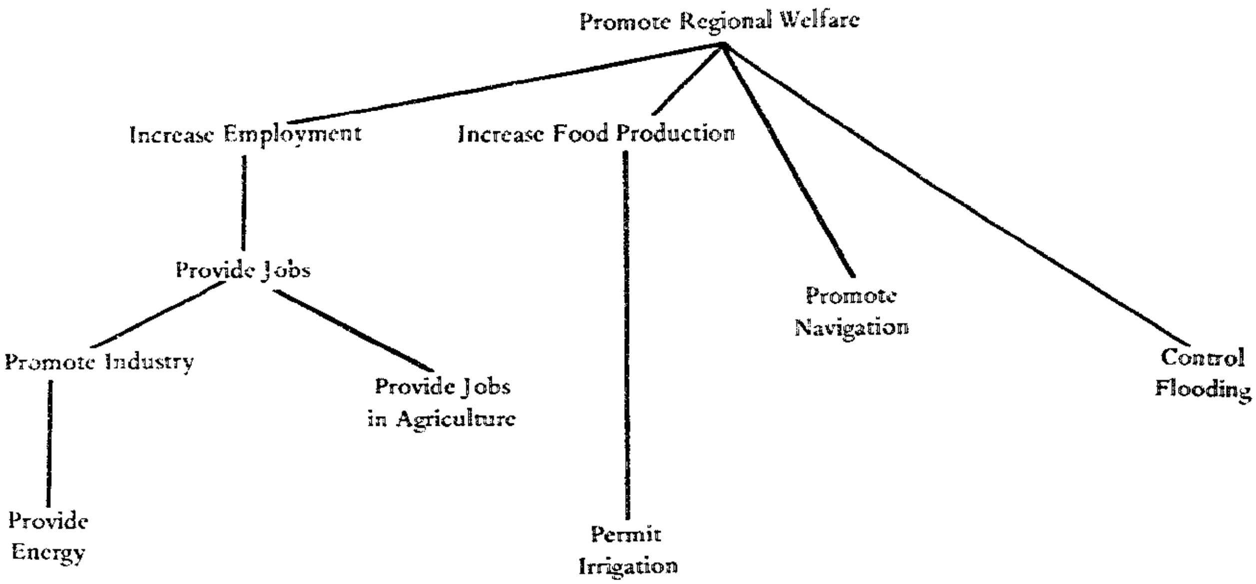
Objective trees may be constructed to aid project design and evaluation. An objective tree consists of project objectives linked hierarchically in a *tree graph*: objectives at a lower level contribute to the attainment of an objective at a higher level (see figure 1). The objectives which are measured to indicate the success of a project are usually found at the lowest level.

Objective trees are one of the many forms of tree diagrams (TRD, page 74) and are closely related to *means-ends analysis.*

ADVANTAGES

1) The objective tree allows a rigorous development of explicit and comprehensive objectives. This helps the design or implementation of a project to achieve the desired ends.

FIGURE 1
An Example of a Partial Objective Tree Developed for a Hydro-Electric Project



2) Since the objectives are made explicit, the diagram is useful to communicate the relationship between objectives to other decision makers and interested groups.

3) Objective trees may incorporate both quantitative and qualitative objectives. Qualitative objectives may be expressed at a lower level of the hierarchy.

4) The process of developing the tree often indicates interlinking or related objectives which might not otherwise be considered.

LIMITATIONS

1) No single objective tree is valid for a particular project. Each person will construct an objective tree in a different manner. There is inherent uncertainty and ambiguity in specifying objectives.

2) The stated and the actual objectives of personnel in an organization may differ significantly. Determining actual objectives is a difficult (if not impossible) task.

3) There may be confusion over means vs. ends. An objective tree structures the statement of goals (or ends) by identifying sub-objective (means) to their attainment.

REQUIRED RESOURCES

SKILL LEVEL

Strong interpersonal skills are useful to successfully obtain the appropriate information for constructing an objective tree. The ability to logically decompose objectives is necessary.

TIME REQUIRED

The time required depends on the ambiguity and uncertainty of the objectives and the level of detail desired for the objective tree. A tree may be constructed within a few hours or over several days, depending on the scope of the project and the clarity of objectives.

SPECIAL REQUIREMENTS

Index cards (or any small uniform blank card) are useful for laying out objectives in a hierarchy.

DESCRIPTION OF TOOL

SUPPLEMENTAL DEFINITIONS

The following definitions are illustrated in figure 2:

1) A *quantitative objective* represents a quantifiably verifiable end or result.

2) A *binary-event objective* either clearly occurs or does not occur.

3) *Qualitative objectives* are judged subjectively to determine if they have been accomplished.

4) A *deterministic measurement* of an objective is where the realization of the objective is unequivocally determined from numerical data.

5) A *probabilistic measurement* of an objective occurs when the attainment of the objective may not be determined with certainty, e.g., because of variability of the data.

6) A *logical measurement* determines whether a binary-event objective has or has not occurred.

7) An *axiological measurement* involves value judgments, where the data necessary to determine accomplishment of an objective are gathered via subjective methods, e.g., interviews (IVW, page 23) or surveys (SVY, page 36).

REQUIRED INPUTS

One step in designing an objective tree involves classifying the types of objectives. Warfield and Hill (1972) classify objectives according to whether they are *quantitative*, *binary-event*, or *qualitative*, as well as by the method used to measure the attainment of the objectives. These classifications are shown with examples in figure 2.

A quantitative objective may be measured either by deterministic or probabilistic methods. A deterministic measurement is made when definite attainment of an objective is determined from numerical data.

A probabilistic measurement is made when the collected data are insufficient to determine with certainty that an objective has been attained. This is the case when data are collected on only a sample of the target population (see Surveys, SVY, page 36).

A binary-event objective clearly occurs or does not occur. Logical measurement is used as a basis for determining whether a binary-event objective has occurred.

Qualitative objectives are those judged subjectively to decide if they have been attained. Axiological measurement, or measurement which is judgmental yet more or less evident, may be accomplished through interviews (IVW, page 23) or surveys (SVY, page 36).

TOOL OUTPUT

The output will be an objective tree which identifies and links objectives (see figure 1). This is essential for other tools, e.g., Intent Structure (INS, page 55) and Planning, Programming, and Budgeting (PPB, page 236).

IMPORTANT ASSUMPTIONS

The major assumption underlying the objective tree is the hierarchical relation between objectives. The objectives for a project may be uncertain or ambiguous because they have not been articulated by the interested parties, and because goals are not constant over time. The objective tree technique assumes that the objectives higher in the tree are less variable over time, and that they are shared by a larger number of interest groups (Granger, 1964).

The assumption that qualitative objectives can be subdivided into quantifiable sub-objectives is implicit in the technique. Its validity does not affect the use of the objective tree to explicitly reveal goals and ends, whether they are measurable or not.

FIGURE 2

Examples of Quantitative, Binary-Event and Qualitative Objectives Classified by Methods of Measurement

Quantitative Objectives

Deterministic Measurement

1. To achieve annual sales of at least $150,000,000
2. To build 150 low-income houses
3. To ship 500 units of the product
4. To increase the school's teacher-student ratio to 40 per 1000
5. To obtain charitable contributions exceeding $100,000.

Probabilistic Measurement

1. To achieve a TV viewing of at least 10 million
2. To produce the product with no more than 1% defective
3. To persuade at least 90% of the drivers to wear seat belts
4. To reduce the crime rate by 50%
5. To increase life expectancy by 10 years.

Binary-Event Objectives

Logical Measurement

1. To land the plane safely
2. To find the lost ship
3. To acquire the new subsidiary
4. To complete construction of the hospital
5. To land a robot on Mars and bring it back safely in this century.

Qualitative Objectives

Axiological Measurement

1. To improve the appearance of the product
2. To provide a pleasant and comfortable ride for passengers
3. To improve the health of the citizens
4. To build a beautiful library
5. To improve employee morale.

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METHOD OF USE

GENERAL PROCEDURE

When beginning the construction of an objective tree, one should not strive for perfection. Initially, getting started is important, for the interaction between objectives cannot become apparent until an initial framework or tree has been constructed. As the tree evolves, one begins to consider more carefully and refine the tree. Based on the work of Warfield and Hill (1972), the following steps are recommended.

1. Generate an initial list of objectives.
   1.1 Define the problem area.
   1.2 Identify the people who will be involved in designing or directing the project.
   1.3 Elicit their project-related objectives.
   1.4 Identify as many project objectives as possible, without attempting to structure the objectives.

2. Identify an overall objective.
   2.1 Identify an overall objective for the project, to which all other objectives will relate. This objective will reflect a value judgment, and it will need axiological measurement. Examples of such objectives are: "to meet the needs of the community" or "to achieve equality in housing benefits."
   2.2 This objective is positioned at the first level of the tree, i.e., at the top of the tree. All other objectives will be positioned below it.

3. Extend the tree one level down.
   3.1 Select objectives for the next level down from the list generated in step 1, or generate additional objectives by asking "what are the sub-objectives necessary to accomplish these objectives?" This is the branching rule for this type of tree diagram (see Tree Diagrams, TRD, page 74).
   3.2 Draw lines on the tree to connect these lower level objectives to the objective they help achieve.

4. Extend the tree to the next lowest level.
   4.1 Choose one of the objectives listed at the current lowest level of the tree. Identify the sub-objective(s) which help to achieve it.
   4.2 Repeat step 3 for all other objectives at the level most recently constructed. Another level of objectives results when all the objectives in this level are dealt with.

5. Review the tree.
   5.1 Review the tree constructed so far. It may be found that:
      a) Some objectives are missing;
      b) An intermediate level of objectives may be added;
      c) It is possible to extend the tree upwards from the first (top) level; or
      d) An objective at a level is seen to achieve more than one objective at some higher level. In this case, redefinition of the objectives is necessary.
   5.2 If the tree appears complete, go to step 6. Otherwise, return to step 4.

6. Check the measurability of lowest level objectives.
   6.1 Take an objective at the lowest level of the objective tree. Ask the question: Is this objective measurable? This is the stopping rule for the tree diagram. The measurability of an objective depends on two processes:
      a) The selection of a measure or unit by which the attainment of objectives will be assessed. (This measure or unit should be objectively verifiable.)
      b) The design of a measurement scale and data collection process, to aid in determining the degree to which an objective may be reached (see Rating Scales, RTS, page 29).
   6.2 Generally the objectives at the lowest level will be quantitative or binary-event. Quantitative objectives generally have a numerical threshold to indicate what performance is acceptable.
   6.3 If the lowest level objective is not measurable, then extend the objective down one more level, i.e., return to step 4.
   6.4 Repeat step 5 for each of the lowest level objectives.

EXAMPLE

The government of Temasek was considering the construction of a large hydro-electric power project for Mek River Valley. The dam would form a large reservoir with uses other than driving the power plant turbines. In order to understand the alternative objectives of such a large-scale project, the Minister of Planning asked his staff to develop an objective tree.

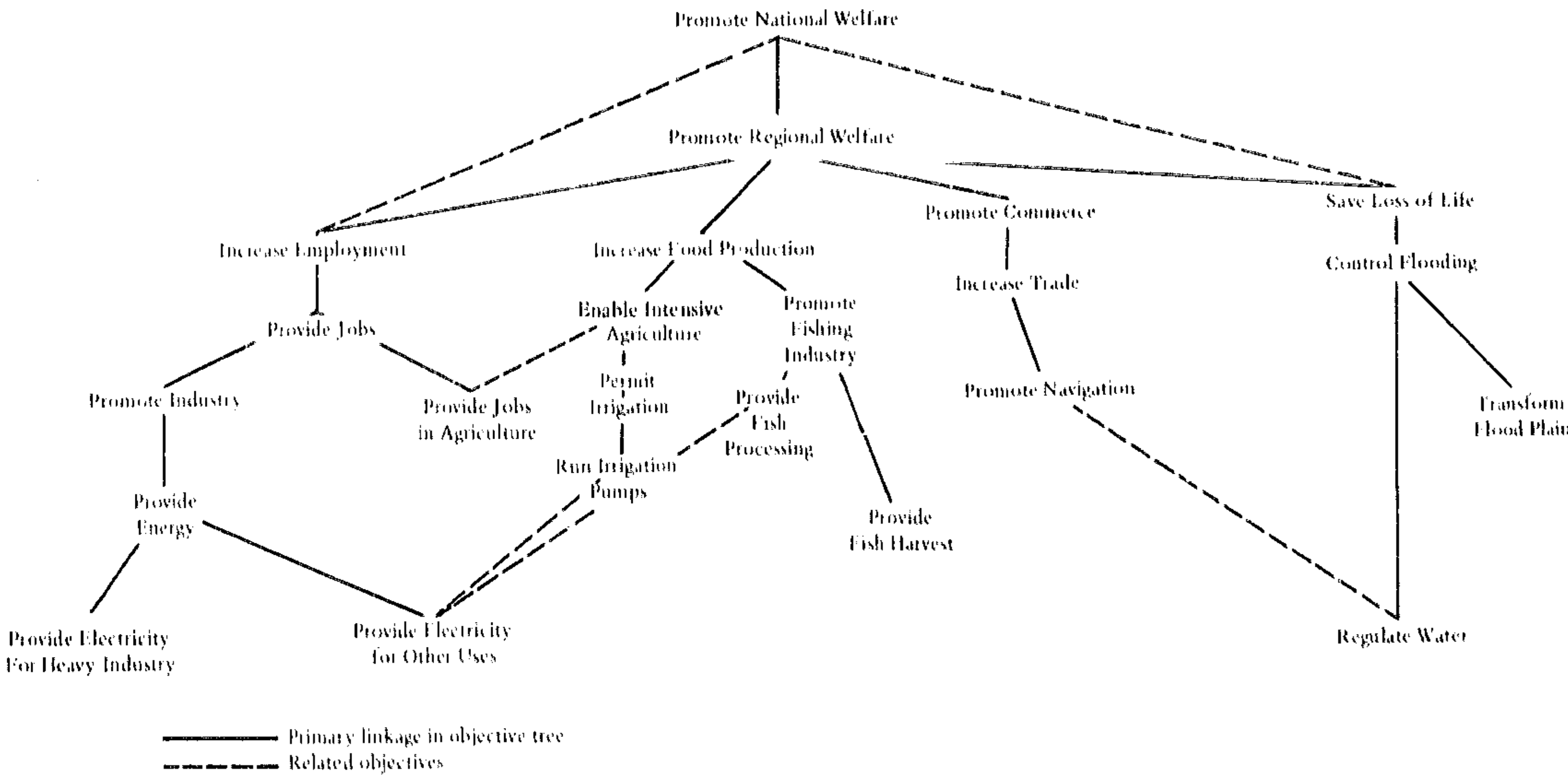
Generating an Initial List of Objectives

The staff identified the problem: provide energy for the growth of the region and country. They assembled a group of industrial leaders, merchants, farmers, and laborers from the region. The Nominal Group Technique (NGT, page 14) was used to identify a list of objectives: provide energy, permit irrigation, promote navigation, control flooding, and promote the welfare of the region.

Identifying an Overall Objective

The group discussed the list and selected the last item as the overall objective. This was the top of the tree. Promoting the region's welfare requires a value judgment since it is not directly measurable. Yet the group shared the view that this was a worthwhile goal.

FIGURE 3
An Example of an Objective Tree Developed for a Hydro-Electric Project



Extending the Tree to Lower Levels

The remaining objectives were positioned in the branches of an objective tree (see figure 1). Then additional objectives were identified, including a higher objective: promote national welfare (see figure 3). This acknowledged that saving lives, increasing employment, and promoting commerce serve higher objectives than those of the region.

One technique for facilitating the construction of the rest of the tree is to list each objective on a separate index card. The index cards may then be laid out on a table to determine their hierarchical relationships. Additional objectives are inserted as needed.

Checking the Measurability of Lowest Level Objectives

The objective tree exercise was completed by considering the measurability of each end of the branches. For example, running irrigation pumps and harvesting fish can be measured quantitatively. However, the transformation of the flood plain is a qualitative objective and must be broken down further in order to identify quantitative measures (e.g., increase in double cropping brought about by farmers who no longer risk flood damage).

Several objectives achieve more than one higher level objective (e.g., providing electricity and regulating water). The staff decided to show the interconnection with broken lines rather than redefining objectives, though the latter may be preferred. Regulating water for irrigation may be at cross-purposes, and the objective tree should reveal this to planners.

This latter point illustrates how the objective tree might be used to influence the scope of the project. The decision makers must decide at which level in the set of objectives the project will be addressed. This in part determines the breadth of of the project, e.g., is the hydroelectric project to address the irrigator's needs as well as the demand for cheap electric power?

This example is developed further in Intent Structures (INS, page 55).

THEORY

The structure of objective trees derives from the theory of graphs and networks (Warfield, 1973). The identification and measurement of the attainment of objectives is rooted in worth assessment and value theory. See, for example, DeNeufville and Stafford (1971).

Interaction matrix diagrams (IMD, page 92) may show the relationships among the multiple objectives. The correspondence between a matrix representation and a tree diagram makes the joint use of the techniques a logical extension of objective trees.

BIBLIOGRAPHY

DeNeufville, R., and Stafford, J.H. *Systems Analysis for Engineers and Managers*. New York: McGraw-Hill, 1971.

Granger, C. H. "The Hierarchy of Objectives." *Harvard Review of Business* (May-June 1964).

Warfield, John N. "Intent Structures." *IEEE Transactions on Systems, Man, and Cybernetics* SMC-3 (March 1973): 133-40.

Warfield, John N., and Hill, J. Douglas. *A Unified Systems Engineering Concept*. Columbus, Ohio: Battelle Memorial Institute, 1972.

Intent Structures

PREREQUISITE TOOLS

Objective Trees (OBT, page 49).

USAGE

PURPOSE

An intent structure defines *objectives*, identifies the *owners* associated with each objective, and describes the logical relationships among the objectives.

USES

An intent structure is used in the same manner as an objective tree (see OBT, page 49). In addition, an intent structure:

1) Distinguishes objectives held by various interest groups.

2) Reveals possible conflicts among sub-objectives.

3) Defines alternative objectives in a logically consistent framework.

KEY DEFINITIONS

1) An *owner* is one or more organizations or persons who possess intent for, or have vested interest in, a project. For example, the Ministry of Agriculture's prime objective is the increase of food production; the farmer has an interest in higher farmgate prices.

2) A *logic element* is a symbol indicating the nature of the relationship between two or more objectives at adjacent levels in a hierarchy.

SHORT DESCRIPTION

Objectives for various interest groups, or owners, are defined and arranged hierarchically so that any objective is achieved only if the specified sub-objectives are realized (see figure 1). The owner(s) of each objective is identified on the diagram.

An intent structure may also show the relation among objectives at different levels by connecting *logic elements* (see figure 2). These specify three possible connections: whether all, any, or only one of the sub-objectives must be achieved in order to attain the higher level objective.

An objective tree is simply an intent structure for which all sub-objectives must be realized, and in which the owner of each objective is not designated. Warfield (1973) developed the intent structure to correct deficiencies in the simple objective tree approach.

ADVANTAGES

An intent structure defines the relationships between objectives so that the analyst is encouraged to think about the various interest groups. Consequently, the intent structure may be employed to clarify thinking, to

FIGURE 1
Format for Intent Structure

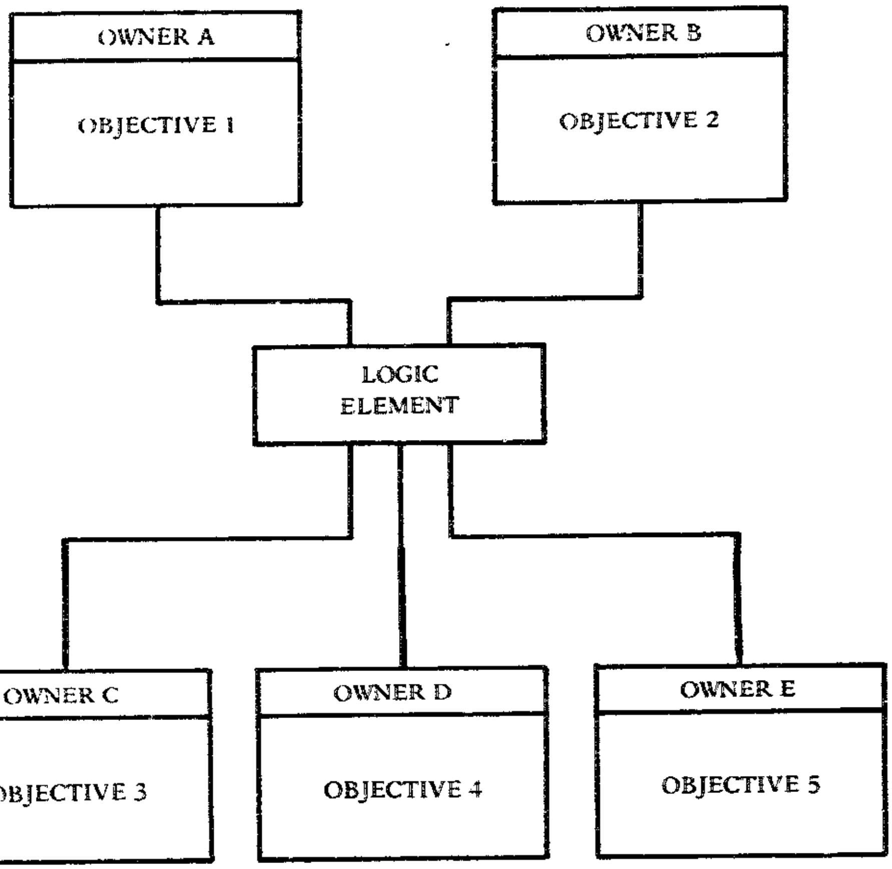


FIGURE 2
Logic Elements for Intent Structures

ELEMENT		LINKING LOGIC
Symbol	Name	For the achievement of the higher level objective:
AND	And	All sub-objectives are necessary
OR	Inclusive Or	Any one or combination of sub-objectives must be attained
XOR	Exclusive Or	Any one, but only one sub-objective must be attained

indoctrinate new personnel, and to identify possible conflicts in objectives.

The logical elements give the analyst the option of describing alternative and interacting objectives, and a means to examine the consistency of relationships.

As the project evolves, the intent structure can be easily modified to incorporate new directions.

LIMITATIONS

There is no single intent structure which is valid for a particular project since people will construct an intent structure differently.

REQUIRED RESOURCES

LEVEL OF EFFORT

The primary task is to identify objectives and associated owners. Representatives of concerned interest groups should be identified for this purpose. The secondary task is to arrange the objectives in an intent structure which reflects the interrelationships of goals.

SKILL LEVEL

In addition to the interpersonal skills necessary to elicit objectives from possibly disparate sources, the analyst must be able to logically sort out the objectives and fill in the missing or unstated sub-objectives. There is no substitute for practice; however, skill at constructing simple objective trees (OBT, page 49) and function expansions (FEX, page 45) is useful.

TIME REQUIRED

If a group discussion technique, e.g., Nominal Group Technique (NGT, page 14) is used to generate objectives, about half a day will be necessary. This does not include the time required to assemble the group. Actual construction of the intent structure should take an additional two to four days, depending on the scope of the project and the number of owners involved.

SPECIAL REQUIREMENTS

The method of construction given in the following sections requires small (3" x 5") cards and tape. Warfield (1973) has developed computer programs for the same purpose.

DESCRIPTION OF TOOL

SUPPLEMENTAL DEFINITIONS

1) The *AND logic element* links sub-objectives to objectives where all sub-objectives must be achieved in order to attain the higher level objective(s) (see figure 3).

2) The *OR logic element* links objectives where the attainment of any one or a combination of sub-objectives will achieve the higher level objective (see figure 4).

3) The *XOR logic element* links mutually exclusive sub-objectives to the higher level objective(s) (see figure 5). One sub-objective alone achieves the higher level objective. Usually the sub-objectives are mutually exclusive only if they are incompatible, or if they compete for the same limited resources.

REQUIRED INPUTS

The intent structure utilizes the input of several people, directly or indirectly associated with the project, to generate the list of objectives. These people and organizational representatives may also be involved in reviewing the finished structure and in modifying it to better reflect their interests relative to the other owners.

TOOL OUTPUT

The most general type of intent structure incorporates both owners and logic elements in a hierarchical structure of objectives (see figure 1). Three modifications are commonly used:

1) The Owner-Free Intent Structure is normally used when the owner is the same throughout the structure, making it unnecessary to list the owner with the objectives.

2) The Logic-Free Intent Structure (or Objective Graph) omits the logic elements from the intent structure. Deletion of the logic may make the intent structure less confusing in some cases, and thus easier to read.

3) The Objective Tree (OBT, page 49) is a special kind of Objective Graph in which the structure of the graph is a tree diagram (TRD, page 74).

IMPORTANT ASSUMPTIONS

Intent structures correct some of the deficiencies which occur when trying to represent complex project objectives as a simple objective tree (see OBT, page 49). However, similar assumptions must hold, i.e., the objectives are discernable and the objectives have some degree of constancy over time. The problem of consensus

FIGURE 3
Use of AND Logic Element

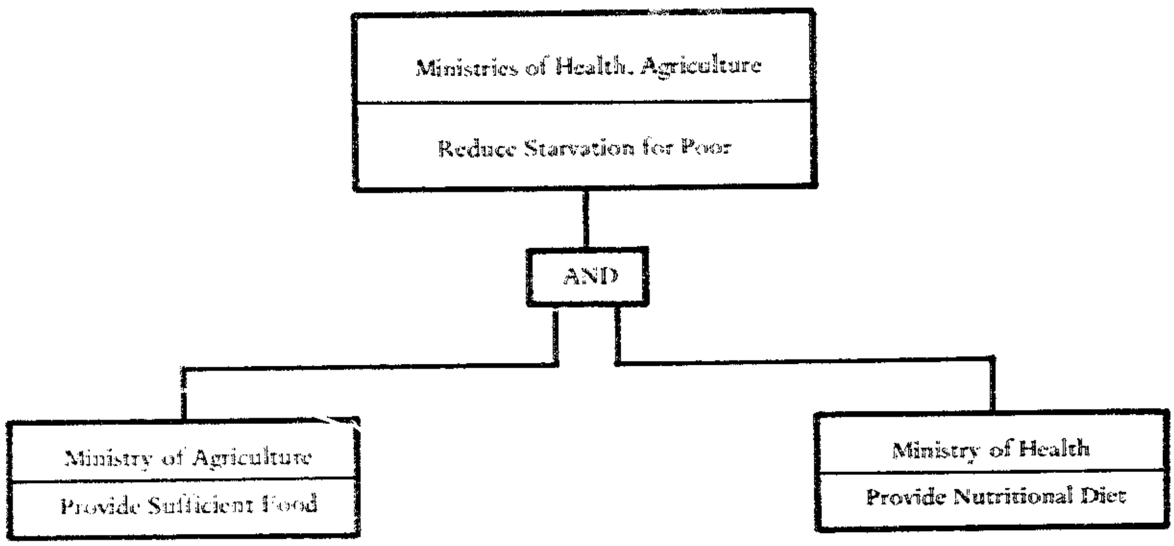


FIGURE 4
Use of OR Logic Element

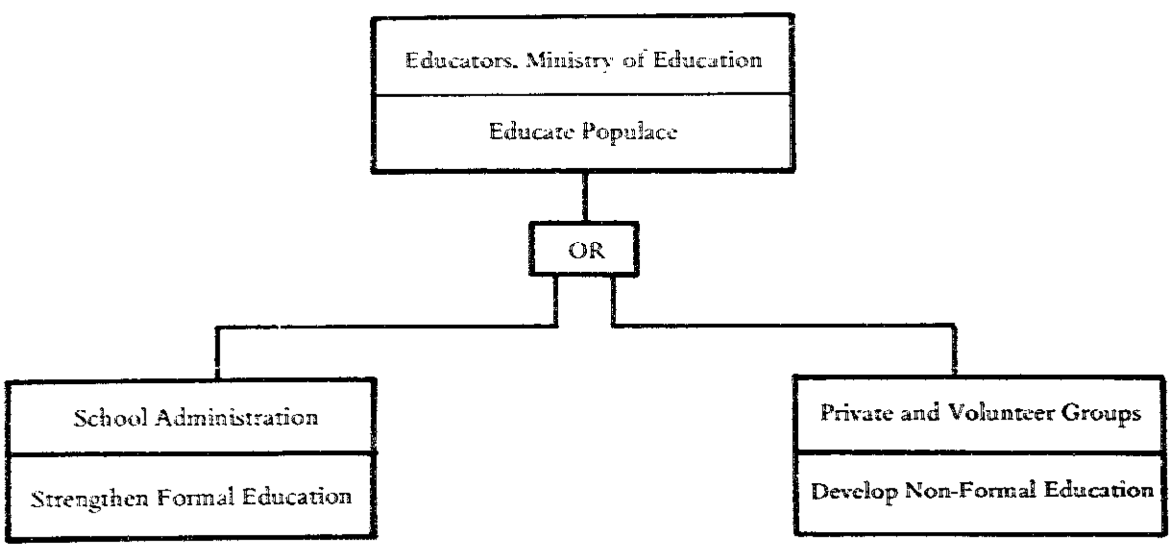
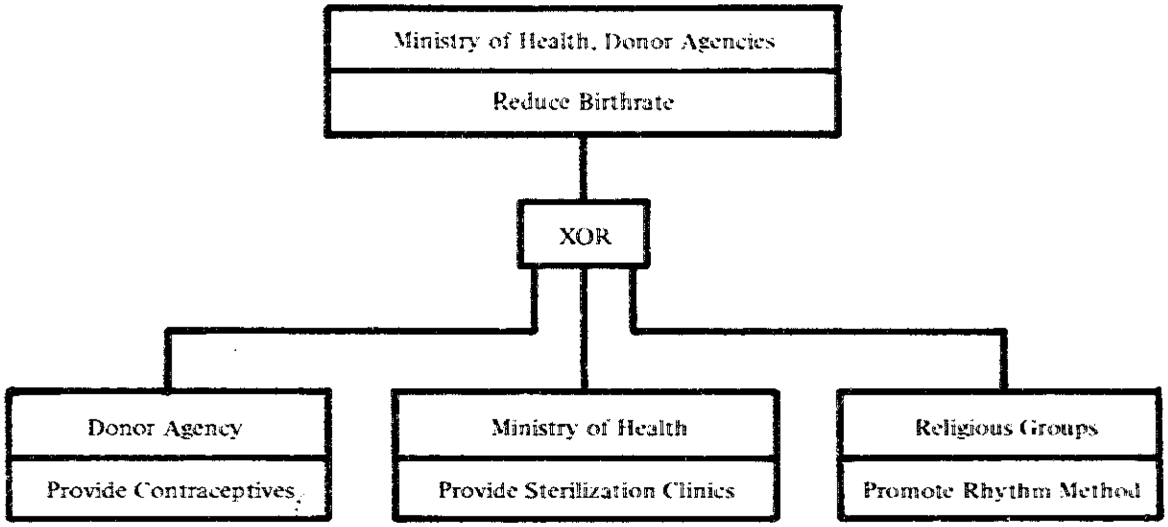
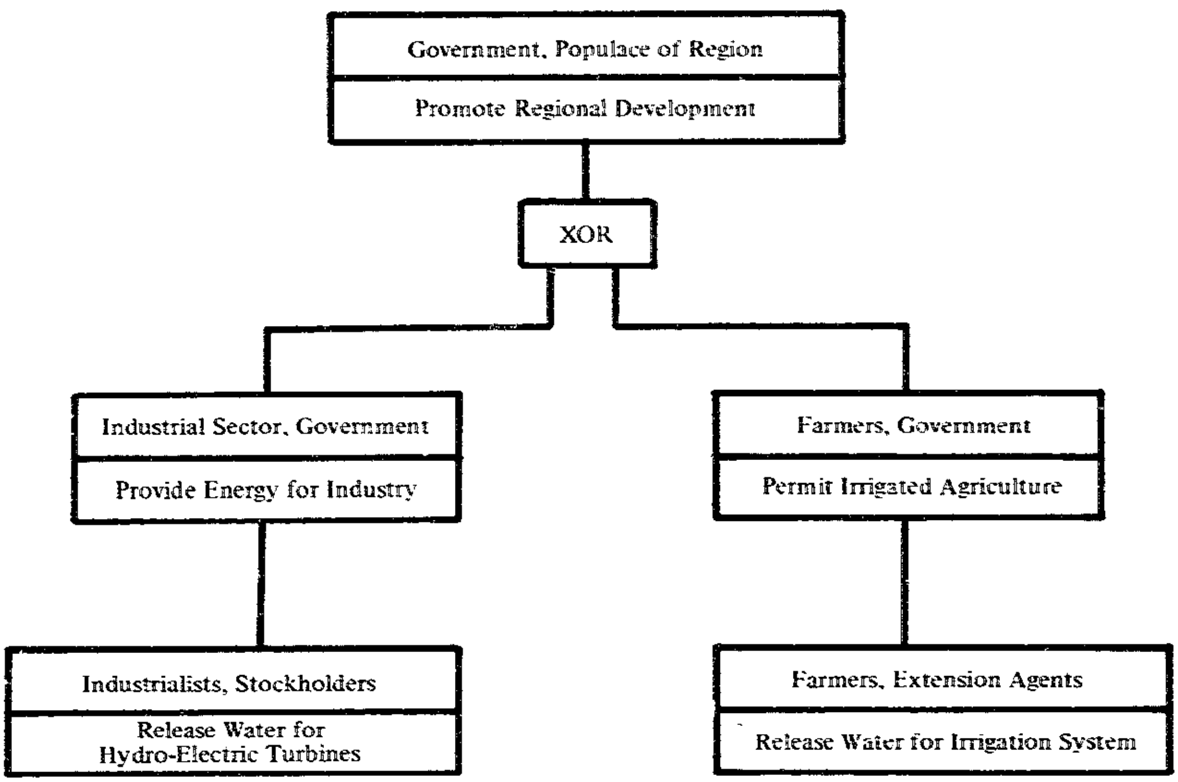


FIGURE 5
Use of the Exclusive OR (XOR) Logic Element

a) Mutually Exclusive Objectives (Means) for Reducing Birthrate



b) Conflicting Objectives for the Use of Reservoir Water



among the various entities associated with the objectives is explicitly treated by identifying owners, assuming that the correct owners can be found.

METHOD OF USE

GENERAL PROCEDURE

Intent structures may be constructed by a procedure similar to the way objective trees (OBT, page 49) are developed (Warfield, 1973).

1. **Generate a list of objectives.**
   1.1 Identify the owners and owner representatives who have an interest in the project.
   1.2 Generate as many objectives as possible. Make no attempt to structure the objectives. Brainstorming (BSG, page 3) or Delphi (DLP, page 168) may be used to elicit the opinions of the owners/representatives.

2. **Construct an intent structure.**
   2.1 Write each objective on separate cards and indicate its owner(s).
   2.2 Lay the cards on a flat surface. Begin arranging them in an intent structure. Note:
      a) If objective A must be accomplished in order to accomplish objective B, A lies below B in the structure.
      b) If accomplishment of objective C, either separately or in combination with other objectives, represents an alternative way of accomplishing objective D, C lies below D in the structure.
   2.3 In arranging the cards, begin with any objective level. It is not necessary to begin with the objective at the top of the structure.
   2.4 If, in the process of arranging the objectives, some objectives are missing or are irrelevant, then add new objectives or discard them.
   2.5 Once a suitable arrangement has evolved, tape the cards to a large sheet of paper.
   2.6 Review the intent structure to see if the arrangement is logical.

3. **Incorporate the logic elements (optional).**
   3.1 Introduce the logic elements into the intent structure by asking if all, any, or only one of the linked sub-objectives must be met in order to attain each objective higher in the structure.
   3.2 Re-examine the owners associated with each objective in light of the logical links between sub-objectives.
   3.3 If necessary, redraw the diagram for distribution to others (e.g., representatives of "owner" organizations). Include a simple key for the logical elements (see figure 2).

EXAMPLE

An objective tree was developed for a hydro-electric reservoir project (see OBT, figure 3, page 53). The objectives for the project included generating energy, permitting irrigation, promoting the fishing industry and navigation, and saving lives and damage through flood control.

An intent structure was prepared which expands on the original objective tree (see figure 6). It included some of the owners of the objectives and the logic elements relating the sub-objectives to higher level objectives. The owners of each of these objectives could be identified in most cases, e.g., farmers desiring irrigation, shippers wanting navigation facilitated, the government and citizens wanting jobs.

All the higher level objectives were brought together under the objective "PROMOTE THE REGIONAL WELFARE" through the logical "OR" relation. Regional welfare is promoted by achieving any one or more of the sub-objectives. However, one might argue that the logic element should be an "exclusive OR" (XOR) because sub-objectives are conflicting. For example, releasing water for irrigation may be completely counter to providing a uniform flow for turbines. The competition between certain sub-objectives can be shown on the intent structure using the logic elements which connect the objectives.

THEORY

Intent structures have been developed by Warfield (March, 1973a), supported by the Battelle Memorial Institute.

Warfield (April, 1973) applies the intent structure technique to the analysis of a U.N. Document, "Towards Accelerated Development: Proposals for the Second United Nations Development Decade," published in 1970. Warfield's intent structure reveals ways to build on a committee planning approach "as well as some of the weaknesses of its [the committee's] product" (page 8-1). In particular, Warfield examines the logic and consistency of the relations among the stated objectives.

This application of the technique emphasizes the utility of the intent structure as a basis for logical analysis of project purposes and goals. The logical relationships between objectives permit the structuring process to be automated on a computer (Warfield, March 1973b). Then, through computer manipulations, the hierarchical relationships are constructed by synthesizing the simple subjective judgments of the relationship between each two objectives. These latter judgments are still the domain of humans, as is the identification of objectives. These points are explored further in Interaction Matrix Diagramming (IMD, page 92).

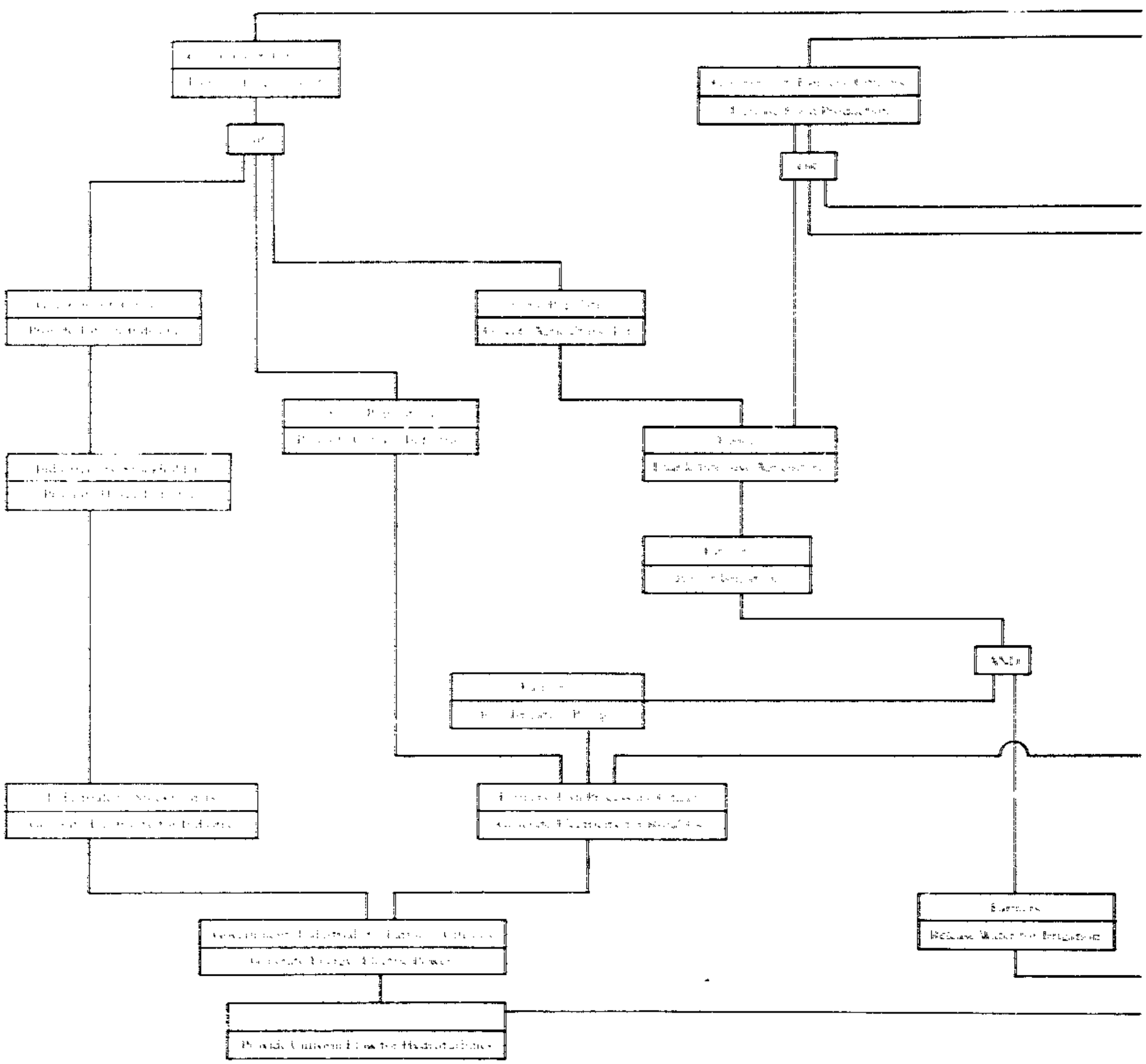
BIBLIOGRAPHY

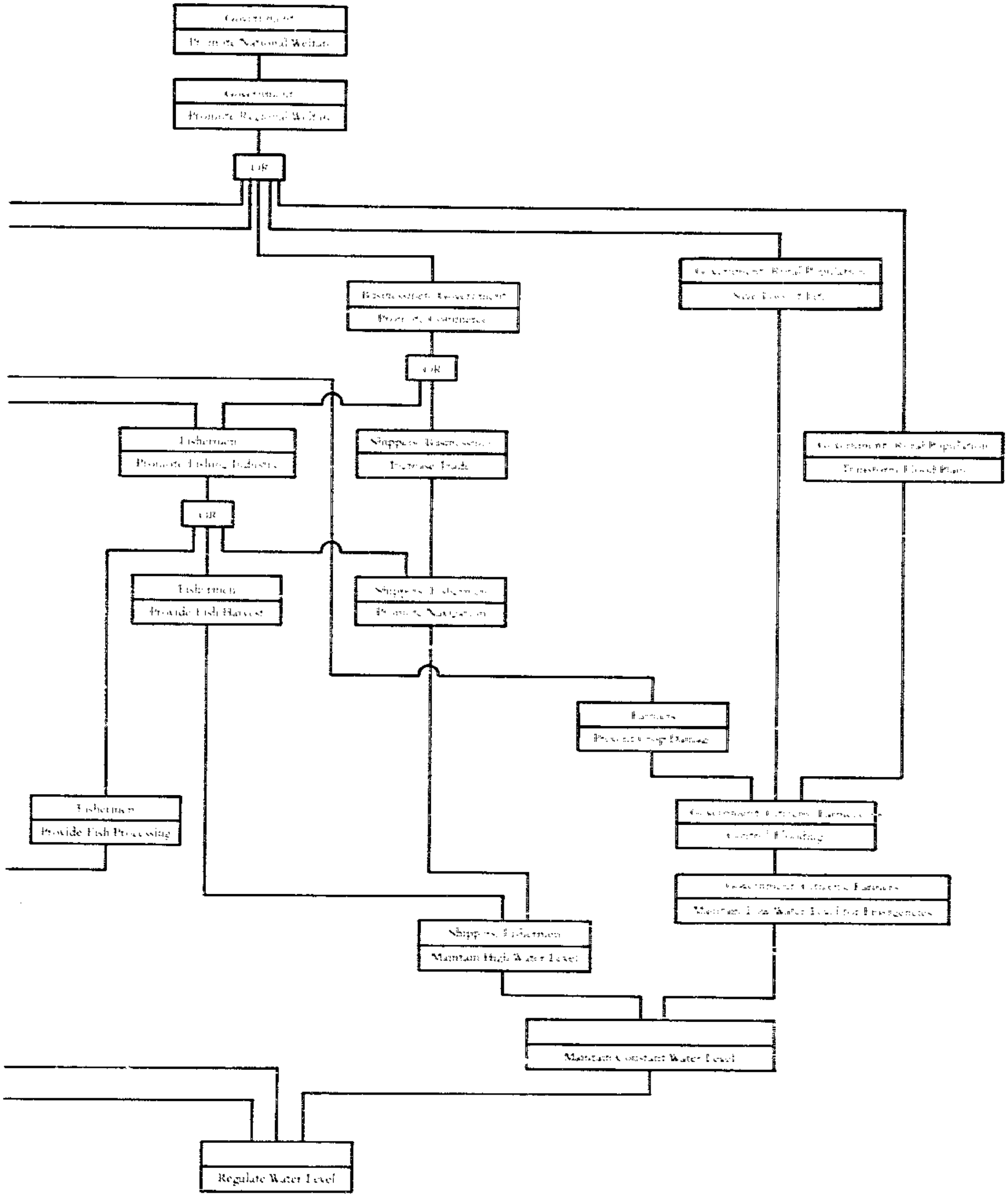
Warfield, John N. *An Assault on Complexity*. Battelle Monograph No. 3. Columbus, Ohio: Battelle Memorial Institute, April 1973.

Warfield, John N. "Intent Structures." *IEEE Transactions on Systems, Man, and Cybernetics* SMC-3 (March 1973a): 133-40.

Warfield, John N. "On Arranging Elements of a Hierarchy in Graphic Form." *IEEE Transactions on Systems, Man, and Cybernetics* SMC-3:2 (March 1973b): 121-31.

FIGURE 6
Intent Structure for Hydro-Electric Reservoir Project





OR
Fishermen
Promote Fishing Industry
Shippers, Businessmen
Increase Trade
Fishermen
Provide Fish Harvest
Fishermen
Provide Fish Processing
Shippers, Fishermen
Maintain High Water Level
Maintain Constant Water Level
Regulate Water Level

IV

Describing Complex Relationships

System Definition Matrix
Tree Diagrams
Oval Diagramming
Interaction Matrix Diagramming

A system is a collection of components which interacts to achieve a specific function or purpose. This versatile concept permits the analyst to describe the problem and prescribe a solution (System Definition Matrix). Identifying the salient variables and describing the relationships among them is a necessary ingredient in the systems approach. Each of the tools in this section approaches this problem in slightly different ways. Hierarchical relationships (Tree Diagramming), causal loops and feedback relationships (Oval Diagrams), and cross-interaction relationships (Interaction Matrix Diagrams) present approaches to structuring complex relationships. These techniques rely primarily on visual representations to define the system and are linked by a common example. The problems of nomad pastoralists are described as a system of ecological, economic, and social-cultural variables and relationships.

System Definition Matrix

PREREQUISITE TOOLS

None.

USAGE

PURPOSE

The System Definition Matrix is a prescriptive model for identifying the conditions and details that need to be specified in developing a plan or design. It is also a *descriptive model* for understanding and specifying the *components* of a *system* and the interrelationships of the components to the system *function* and *environment*.

USES

The System Definition Matrix may be used as:

1) A comprehensive means for identifying and modeling the essential components of a system in order to communicate and to help understand the system's function in its environment.

2) A *checklist* to guide information-gathering for design or analysis.

3) A format for specifying details of a system design.

KEY DEFINITIONS

1) A *descriptive model* is a representation or imaginary entity containing information in a predefined form, intended to be interpreted by its user rules (Thesen, 1973).

2) *Components* are the entities in a system which may be elemental, or they may be subsystems having distinct components.

3) A *system* is a collection of components which interact to achieve a common function.

4) The *function* is the primary concern of the system. It is the fundamental dimension of purpose. Note that functions are not the goals, or the desired results, of the system. This distinction is further clarified in Function Expansion (FEX, page 45).

5) A *checklist* is used in design or analysis where items are marked or otherwise noted item by item.

SHORT DESCRIPTION

The System Definition Matrix has eight elements (rows of the matrix): *purpose, input, output, sequence, environment, physical catalysts, human agents,* and *information catalysts.*

Each of the system elements can be described in five dimensions (columns of the matrix): *fundamental, rate, control, interface,* and *state dimensions.*

The specification of elements by these dimensions composes the System Definition Matrix (see figure 1).

ADVANTAGES

1) The System Definition Matrix enables clear separation and identification of the interrelationships among

FIGURE 1
System Definition Matrix Format: A Hospital System

DIMENSIONS

ELEMENTS	FUNDAMENTAL	RATE	CONTROL	INTERFACE	STATE
PURPOSE	Treat patients		Malpractice suits filed		Provide preventive care
INPUT	Ill and injured people	50 cases/day	Schedule surgery referrals	Emergency medical service	
OUTPUT	Patients released	40 releases/week	Hospital review board	Outpatient referrals morgue	
SEQUENCE	See flowchart*	Average stay: 2 days	Monthly bed check (random)		
ENVIRONMENT	Location, humidity, temperature Supportive climate		Automatic control, Staff T-group		
PHYSICAL CATALYSTS	Structure: beds, equipment, supplies	Depreciate on 10 year cycle, weekly purchase	Audit quarterly		Double capacity in 10 years
HUMAN AGENTS	Medical staff, secretarial staff, custodial staff		Hospital review board	Medical school system	
INFORMATION CATALYSTS	Staff assignments, patient care, charts planned, referrals			County public health office	Computerized patient care system

*See Flowcharts, FLW, page 107.

components of a system in order to characterize the system structure.

2) It provides a more detailed model than that found in Logical Framework (LGF, page 260).

3) Specifying rate, control, and state dimensions requires a dynamic view of the system. This explicit treatment of time facilitates planning and project control.

4) Simply specifying the fundamental aspects of each element *can* be advantageous, e.g., the breakdown of the system may be used in other tools (for example, Scenarios, SCN, page 164, and Computer Simulation Models, CSM, page 120).

5) Complex systems can be structured by treating each row, column, or cell as a System Definition Matrix. This can be extended as far as necessary to handle the complexities.

LIMITATIONS

1) A somewhat mechanistic approach (input → sequence → output) may not be palatable to project personnel. Describing a project in a matrix may be alien to their way of thinking. Other techniques for characterizing system structure (see Section IV tools) may avoid this.

2) A System Definition Matrix is seldom completely specified since components may not be identifiable, or their specification may not be relevant to the description. Confusion may arise over where a system component belongs in the matrix.

REQUIRED RESOURCES

LEVEL OF EFFORT

Considerable effort is required to completely specify five dimensions for each of the eight elements, particularly since entries in the matrix may be hard to define. However, simply completing the fundamental dimension requires the least effort and may give the greatest return.

SKILL LEVEL

Identifying or specifying matrix entries requires a thorough understanding of each entry in the matrix. Working through examples of familiar systems and comparing them with similar efforts will provide confidence in developing System Definition Matrices. Function expansion (FEX, page 45) is useful in developing relevant skills.

TIME REQUIRED

The time required is directly proportional to the complexity of the system and the degree of matrix completeness desired. For design problems, the degree of creativity one is able to exercise in specifying entries influences the time.

DESCRIPTION OF TOOL

SUPPLEMENTAL DEFINITIONS

1) The *environment* is the set of all factors which are salient to the understanding of systems relationships, but which are outside the influence of the system variables.

2) *Inputs* are the people, information, and/or physical items which enter the system to be transformed by a sequence into outputs of the system, e.g., the raw materials of the project.

3) *Outputs* are the desired and undesired results of the transformation process of a system. The desired results enable the system to achieve its function. Patients leaving a hospital, cured or not, are outputs of a hospital system.

4) A *sequence* is the process by which the inputs are worked on, transformed, or processed into outputs, usually with the aid of catalysts, e.g., the steps in diagnosing, treating, and curing a patient.

5) *Physical catalysts* are the equipment, facilities, etc. which are necessary for the inputs to be transformed into outputs, but which are not themselves inputs or outputs of the system.

6) *Human agents* are the personnel who may be necessary for the system to achieve its function, yet are not themselves inputs or outputs of the system, e.g., medical staff for a hospital system.

7) *Information catalysts* are the communication (written or verbal) and the knowledge which enable the system process to occur, yet which are not inputs or outputs of the system, e.g., staffing assignments at a hospital.

8) A *fundamental dimension* is the basic characteristic of the eight system elements. The hospital building is the fundamental dimension of the physical catalyst element of the hospital system.

9) The *rate dimension* is the performance measure for a system element. For example, a hospital system may have as its input 50 new cases per day; the rate dimension of output may be 40 releases per week.

10) The *control dimension* evaluates and regulates any element's specification, e.g., more than two mortalities per week (rate dimension of output) in a surgery unit may result in corrective action (control dimension) by the Hospital Review Committee. This dimension measures each element as the system operates, compares the measure to what is designed or desired, and takes action if the difference is greater than desired.

11) *Interface dimension* is the relation to other systems or elements—a linking entry to related System Defi-

FIGURE 2
System Definition Matrix in List Format for Alcoholics Treatment Center

Function

Fundamental Dimension:	Treat alcoholics
Rate Dimension:	Reduce alcoholism
Control Dimension:	County department of health review
Interface Dimension:	Disease treatment
Future State Dimension:	Treatment centers expand to meet rising demand

Input

Fundamental Dimension:	Clients
Rate Dimension:	Approximately ten per day
Control Dimension:	Check that no more than two turned away per month
Interface Dimension:	Client identification, clean bedding from laundry system
Future State Dimension:	In five years may take drug referrals, eliminate repeaters

Output

Fundamental Dimension:	Detoxified clients
Rate Dimension:	100 percent release
Control Dimension:	Check for subsequent referral
Interface Dimension:	None
Future State Dimension:	Not specified

Sequence

Fundamental Dimension:	Sign in, contact relative, detain, examine, release
Rate Dimension:	Detain 24 hours, notify relatives within 2 hours
Control Dimension:	Check that no clients detained more than 48 hours
Interface Dimension:	Physical examination system
Future State Dimension:	Not specified

FIGURE 2
Continued

Environment

Fundamental Dimension:	Social: unsupported, political, decriminalized treatment, physical: pleasant surroundings
Rate Dimension:	N.A.
Control Dimension:	Atmosphere should not condone behavior, no coddling
Interface Dimension:	Not specified
Future State Dimension:	Not specified

Physical Catalysts

Fundamental Dimension:	Beds, toilets, hot coffee
Rate Dimension:	Ten beds available per night
Control Dimension:	Check for clean bedding
Interface Dimension:	Laundry system for bedding
Future State Dimension:	Not specified

Human Agents

Fundamental Dimension:	Social worker, family counselor (police), physicians aid
Rate Dimension:	24-hour staff on hand
Control Dimension:	Shift staff to maximum use hours
Interface Dimension:	Police referral, Alcoholics Anonymous
Future State Dimension:	Not specified

Information Catalysts

Fundamental Dimension:	Admission and release forms, client identification
Rate Dimension:	N.A.
Control Dimension:	Four weeks supply of forms on hand as safety stock
Interface Dimension:	Police record system
Future State Dimension:	No police record in three years

nition Matrices, e.g., the input of a hospital system is linked to the output of an emergency transport service.

12) *State dimension* is a specification of anticipated changes and plans in specific time horizons for each of the four dimensions. For example, expanding the number of beds (physical catalyst) in two years or physicians (human agents) in three years at a hospital.

REQUIRED INPUTS

The primary input for specifying or developing a descriptive System Definition Matrix is to gain a familiarity with the existing system. For designing or planning a system, see IDEALS (IDL, page 231).

TOOL OUTPUT

The output is the System Definition Matrix with a partial or complete specification of elements and dimensions. The System Definition Matrix may then be used in other tools, such as Scenarios (SCN, page 164), Gaming (GAM, page 124), Cost-Benefit Analysis (CBA, page 212), and Computer Simulation Models (CSM, page 120). The IDEALS Strategy (IDL, page 231) uses the System Definition Matrix as a format to specify results.

An alternative breakdown of system elements which describes public service agencies may be used to avoid the input → sequence → output terminology. The terminology avoids the jargon used for the System Definition Matrix elements. The list and questions which may be associated with each element (and the corresponding matrix element) are:

Purposes (function): Why? What is the mission?
Background (information): What do I know? What are their previous states?
Clients (inputs): Who? What are their present states?
Results (outputs): What are the changed states of clients?
Method (sequence): What ways? How to get results?
Setting (environment): What is political or social atmosphere?
People (human agents): Who are the doers?
Facilities (physical catalysts): What is needed to do it?
Dollars (inputs): What are the costs?

IMPORTANT ASSUMPTIONS

The development of a System Definition Matrix assumes that a system can be broken down morphologically into distinct components. The distinction between inputs, outputs, and catalysts may often be blurred. This is particularly true if the same set of components is involved in quite different functions. For example, hospital staff are human agents in a patient treatment system and inputs to the hospital management control system.

METHOD OF USE

GENERAL PROCEDURE

The development of a System Definition Matrix may be a creative as well as an analytical exercise. Consequently, involving knowledgeable staff is productive. Nominal Group Technique (NGT, page 14) or brainstorming (BSG, page 3) may be used to discover entries.

The procedure begins with function specification, but may repeat and backtrack as necessary.

1. **Specify the function.**
   1.1 Discuss the system to determine its function (a function expansion, FEX, page 45, may be used).
   1.2 Proceed to the fundamental specification of other elements before specifying the other four dimensions of the system function.

2. **Identify inputs and other system elements.**
   2.1 Try to complete all the entries for the fundamental dimension column of the matrix.
   2.2 If a list format is being used, skip dimensions of rate, control, etc. and return to them after other elements have been specified. An alcohol workshop identified the inputs for the treatment system as "clients with a drinking problem" (see figure 2).

3. **Complete the dimensions for each element.**
   3.1 Complete the rate, control, and state dimensions for all elements except function. It may not be possible to specify all cells in the matrix, and they may be temporarily left blank.
   3.2 If an element of the system does not include a particular dimension, indicate "none required" or "not applicable, N.A." in the matrix to show that the possibility has not been overlooked, e.g., there may be no control dimension for system inputs. Figure 2 contains a description of a partially specified alcoholic treatment system.

4. **Complete system function dimension.**
   4.1 Complete the dimension specifications of system function if possible.
   4.2 In this row, indicate foreseeable changes to the system function.
   4.3 Note interfaces with other systems.

5. **Complete interface dimensions.**
   Where appropriate, complete the interface column of the System Definition Matrix for the eight elements. For example, the alcoholic treatment system inputs (clients) may interface with the output of public service agencies (e.g., the police).

6. **Check the matrix for completeness.**
   Fill blank cells as additional information is gathered.

7. **Repeat process to desired level of detail.**
   Repeat the process for particular cells. For example, the control dimension of system output may suggest a subsystem whose function, inputs, outputs, etc. may be specified in a separate matrix. In this way, a very detailed morphological breakdown of a system and its subsystems may be modeled.

EXAMPLE

Figure 2 presents a partially specified System Definition Matrix (in list format) for an alcoholic treatment system.

THEORY

The theoretical basis for the System Definition Matrix is founded in the theory of systems. In defining what is meant by a system, different terminology and levels of detail may be used, but essentially a descriptive model is developed.

The System Definition Matrix imposes a morphological structure on a conceptual model to produce a description of the system components. This may differ from similar systems descriptions in the explicit treatment of system functions and dimensions of rate and future state. Nadler (1970) is responsible for the System Definition Matrix format, particularly the emphasis on function and the explicit treatment of catalysts.

BIBLIOGRAPHY

Nadler, G. *Work Design.* Homewood, Ill.: R. D. Irwin, 1970.

Nadler, G. *Work Systems Design: The IDEALS Concept.* Homewood, Ill.: R. D. Irwin, 1967.

Thesen, A. "Some Notes on Systems Models and Modelling." *International Journal of Systems Science* 5 (1973): 145-52.

Tree Diagrams

PREREQUISITE TOOLS

None.

USAGE

PURPOSE

A tree diagram illustrates a set of complex relationships by fitting them into a *hierarchy* of related factors.

USES

Tree diagrams are used to:

1) Describe the relationships among objectives of a project (see Objective Trees, OBT, page 49).

2) Describe the relationships among alternatives, as in *means-ends analysis* or Decision Trees (DTR, page 141).

3) Clarify sequences of relationships in Interaction Matrix Diagrams (IMD, page 92).

4) Develop relationships among variables of a system as in *influence trees* which may then be redrawn as oval diagrams (OVD, page 81).

5) Provide a measure of the degree of relatedness among different sets of factors, as in *relevance trees*.

KEY DEFINITIONS

1) A *hierarchy* is an ordered structure illustrating which factors are subordinate to others.

2) *Means-ends analysis* is the identification of alternative actions to achieve specified ends.

3) An *influence tree* diagrams the variables which influence other variables which are higher in the tree.

4) A *relevance tree* diagrams the relationships among different sets of factors at each level of a hierarchy.

5) A *model* is a representation or an imaginary entity that contains information in a certain predefined form and has specified rules for interpretation (Thesen, 1973).

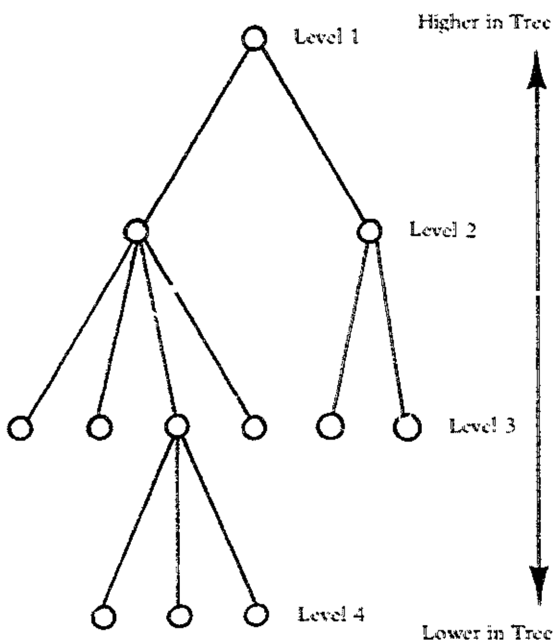
6) A *tree graph* is a set of linked elements where only one link exists between any two factors (see figure 1).

7) A *branching rule* governs the construction of relationships in a tree diagram (see figure 2).

SHORT DESCRIPTION

A tree diagram is a *model* which describes a set of relationships by using a *tree graph* (see figure 1). The branching points are factors related to each other according to a *branching rule*. The types of factors shown and the branching rule used are determined by the purpose of the diagram (see figure 2). For example, project objectives are modeled as objective trees (see OBT, page 49) to describe subordinate relationships. More information may be added to the diagram to facilitate analysis and to clarify relationships, e.g., to identify the levels of a relevance tree or to assign weights to alternative outcomes.

FIGURE 1
Tree Graph Form



KEY:
O Factors (variables, objectives, alternatives, etc.)
— Relationships (causal, influence, subordinate, etc.)

ADVANTAGES

A tree diagram is constructed by doing a logical breakdown of complex relationships. The branches of the diagram reduce a set of relationships to its essential components to expedite analysis.

LIMITATIONS

A tree diagram implies a level of determinacy which may be unwarranted. All elements of the diagram can seldom be determined in advance—a fact which must not be overlooked during subsequent analysis.

REQUIRED RESOURCES

SKILL LEVEL

Tree diagramming can be learned rapidly with practice. Because other techniques may be required to make maximum use of the tree diagram, the skill level required depends on the purpose.

TIME REQUIRED

Tree diagrams may be drawn rapidly as the development is usually quite logical. Some time is necessary for information-gathering and analysis, depending on the particular type of tree diagram.

DESCRIPTION OF TOOL

SUPPLEMENTAL DEFINITIONS

1) A *system* is a collection of components which interact to achieve a common function.

2) A *component* of a system is an entity which may be elemental or it may be a subsystem having distinct components.

3) A *stopping rule* determines when any branch of the tree diagram should end.

4) An *influence* relationship occurs when one variable's change in value influences change in another variable, e.g., the ACCEPTANCE OF INNOVATIONS is influenced by the YIELD FROM CROPS.

5) There is a *producer-product* relationship when one variable is a product of the other (e.g., RANGE FEED is a product of AVAILABLE PASTURE).

REQUIRED INPUTS

The purpose of the tree diagram should be clearly established prior to its construction to determine the types of factors to be shown and the relationships to be described. Some familiarity with the problem context is necessary in order to be able to depict relationships and identify factors.

TOOL OUTPUT

Tree diagramming results in a description of a complex set of relationships. Simply developing the tree diagram may be sufficient for gaining an understanding into the structure of relationships and the span of relevance of various factors.

However, tree diagrams are usually the intermediate output of a more detailed analysis, e.g., influence diagrams may be converted into oval diagrams (OVD, page 81), and additional information can be gathered to complete a decision tree (DTR, page 141).

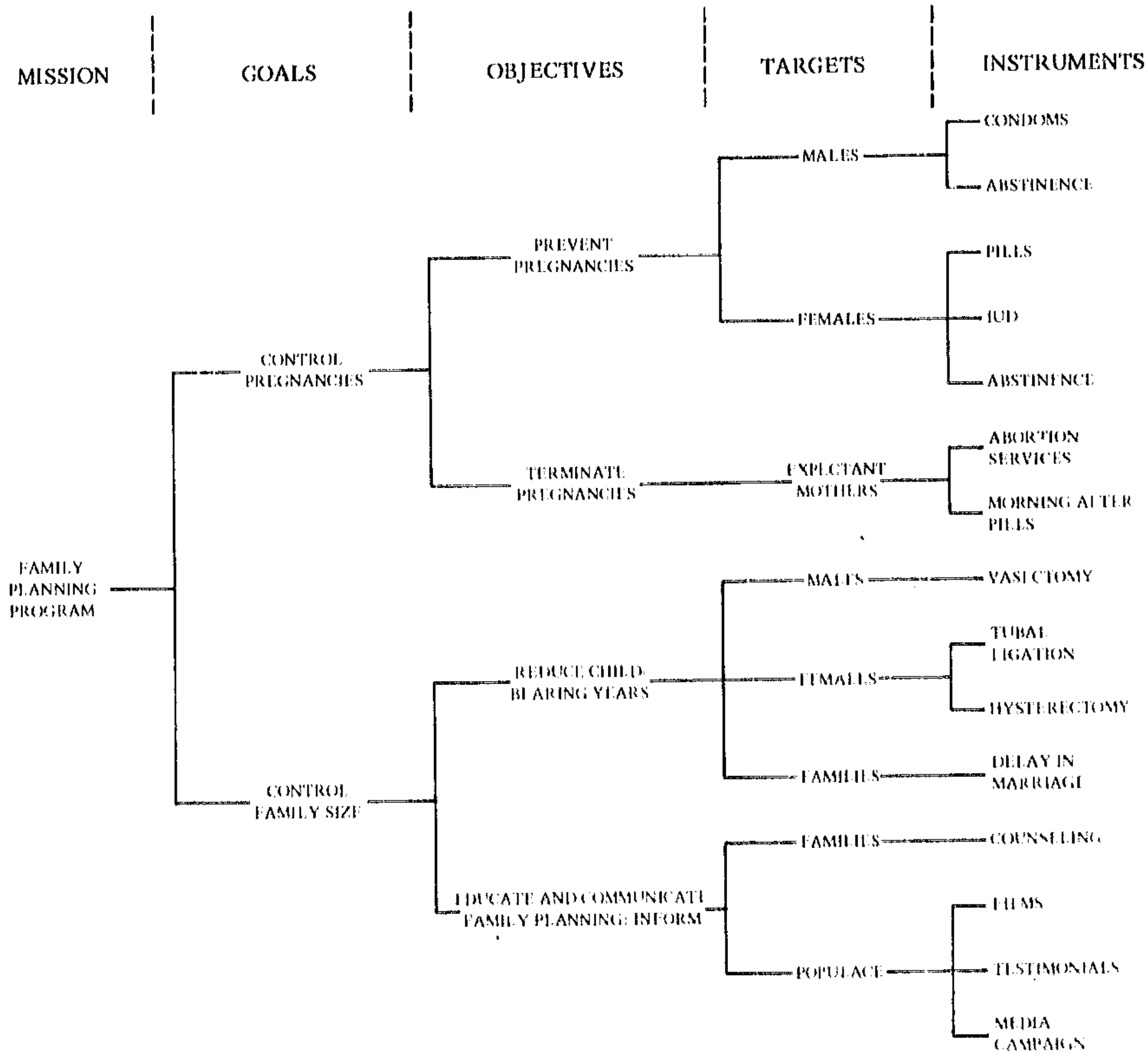
IMPORTANT ASSUMPTIONS

A hierarchical relationship is assumed to exist among the elements of a tree diagram. For example, if the set of complex relationships describes a *system*, then the tree diagram decomposes the system into *components*, each of

FIGURE 2
Fundamentals of Tree Diagram Construction

TREE DIAGRAM TYPE	FACTORS DIAGRAMMED	BRANCHING RULE
INFLUENCE TREE	SYSTEM VARIABLES	IDENTIFY THE VARIABLES WHICH INFLUENCE THE VARIABLE
RELEVANCE TREE	SETS OF PROGRAM FACTORS	IDENTIFY THE FACTORS ASSOCIATED WITH EACH FACTOR IN NEXT HIGHEST LEVEL OF THE TREE
OBJECTIVE TREE	OBJECTIVES	IDENTIFY THE OBJECTIVES NECESSARY TO ACHIEVE EACH HIGHER LEVEL OBJECTIVE
MEANS-ENDS TREE	ENDS AND ALTERNATIVE ACTIONS	WORK DOWN THE TREE: HOW IS THIS ACTION TO BE ACHIEVED? WORK UP THE TREE: HOW IS THIS ACTION TO BE UNDERTAKEN?
DECISION TREE	ALTERNATIVE ACTIONS AND EVENTS WHICH AFFECT OUTCOME OF ACTIONS	IDENTIFY ALTERNATIVE ACTIONS; IDENTIFY EVENTS, REPEAT UNTIL ALTERNATIVES ARE EXHAUSTED.

FIGURE 3
Relevance Tree Examples for Family Planning Program



which may be further broken into components, etc. Or every system may be subdivided into subsystems, and consequently, every system is a component of some larger system.

METHOD OF USE

GENERAL PROCEDURE

1. Determine the type of factors to be shown on the diagram.
2. Determine the appropriate branching rule.
3. Determine the starting factor of the tree.
4. Identify related factors using the branching rule and show them as branches stemming from the starting factor.
5. Determine the appropriate stopping rule.
6. Repeat step 4 for each newly identified factor unless the stopping rule applies.
7. Review the tree for consistency of rule application.
8. Add any information necessary for analysis.

EXAMPLES

Two examples will be used to illustrate the tree diagramming technique. Other applications are found in the Objective Trees (OBT, page 49), Decision Trees (DTR, page 141), and Interaction Matrix Diagrams (IMD, page 92).

Relevance Tree Diagram

A relevance tree can be used to describe the relationships of different elements in a family planning program (see figure 3).

The starting variable is a simple identification of the mission of the program. The branching rule is in four parts:

1) What are the goals which correspond to this mission?

2) What are the objectives which correspond to each goal?

3) What are the targets for each objective?

4) What are the instruments relevant to each target for accomplishing the objective?

Identifying the instruments completes the tree and thus decomposes a complex program into its various elements.

Influence Tree Diagram

Much of the success of this technique depends on the art and expertise of the analyst. The example that follows examines some of the relationships which describe the nomad pastoralism eco-system.

The following excerpts from a description of an M.I.T. study describe the factors affecting the conditions in the Sahel:

> In the Sahel live the nomads, who follow the rains to the north every year and retreat to the south in the dry season. Their numbers have traditionally been limited partially by the number of cows and goats the land was able to support, and by the distance between water holes. Western agencies working in the area during the past decade made the obvious but ill-advised move of digging wells throughout the grazing commons. The numbers of cattle, and people, grew proportionately, using much of the grazing land for the greater part of the year instead of seasonally, allowing the land no time to recover. The herds moving southward during the dry season have been forced to travel over land that has already been overgrazed and, finding water but no forage, have literally starved at the water holes. . . .
>
> It is this widespread overuse that is preventing the land from recovering even when rain does fall. Instead of being absorbed, the rain falling on the vegetation-stripped ground merely washes off the topsoil. The cycle—overgrazing, wind, rain—is causing the desertification of much of the land.*

The variables and relationships which describe the influences on livestock population are shown in figure 4. The starting variable selected was HERD SIZE, an aggregated representation of all domesticated grazing animals in the Sahelian region. NOMAD POPULATION is an equally appropriate starting variable, but the tone of the excerpts suggests that the relationships between animal populations and range conditions are central to describing the eco-system.

The following branching rule was applied to each newly identified variable:

Identify the variables which influence this variable.

Other relationships can be diagrammed by inserting "produces" or "causes this variable to change" in the branching rule. The rule specifies the relationship, whether it is cause-effect, *producer-product*, or simply the influence of one variable on another.

If the branching rule were changed to:

Identify variables which are influenced by this variable,

the direction of influence implied by the tree structure would be reversed. Generally, it is easier to start with observed effects and attempt to identify causes.

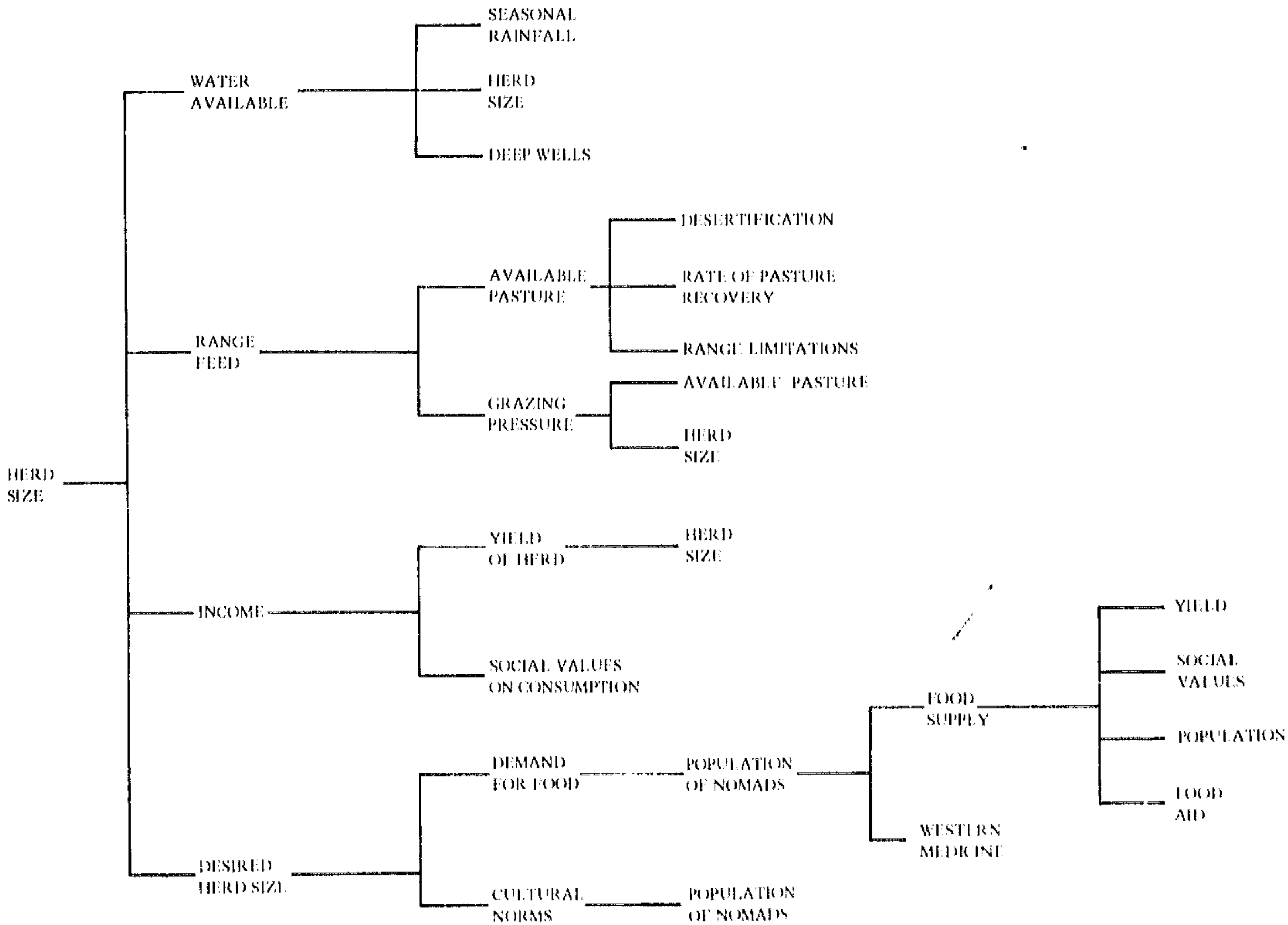
Two stopping rules were used to terminate the branching process:

1) Stop with any variable which is already shown on the diagram, or

---

*S.J.N., " 'Tragedy of the Commons' in Africa," *Technology Review* (October-November, 1974), pp. 73-74.

FIGURE 4
Influence Tree Diagram for Nomad Pastoralism Eco-System



2) Stop with any variable which is considered outside the purpose of the system, and which is not likely to be influenced by any other factor previously identified.

Rule 2 applied for variables like SEASONAL RAINFALL and SOCIAL VALUE ON CONSUMPTION (see fig. 4). Assuming that the eco-system functions to sustain life on the Sahel, these variables are considered outside the influence of factors within the system.

Rule 1 applied several times (e.g., HERD SIZE) and was employed to avoid redundant branching. When numerous branches terminate with the same variable, an oval diagram is a more economical form of representation for the complex relationships. This example is continued in the description of the oval diagramming technique (OVD, page 81).

THEORY

Tree diagrams are rooted in graph theory and the representation of hierarchical relationships (Warfield, 1973). The adoption of tree graphs for the tree diagramming technique relates more closely to systems theory than to mathematical topology.

Warfield (1974) has described the structural representations of complexity which emphasize the correspondence between a matrix and a graph of relationships. A tree diagram may be used to trace the linkages in an interaction matrix diagram (IMD, page 92) in order to clarify the interactions.

The decomposition of a set of complex relationships by techniques, which Harrison (1972) has called a process of "repeated-subdivision," assumes that the relationships form a hierarchy. The hierarchy may be a chain of cause-effect relationships, the nesting of one set of components within a larger component of a system, or the ordering of objectives from the specific to the general.

Relevance trees have been discussed extensively in the technological forecasting literature (Alderson and Sproull, 1972) as one of the more useful qualitative techniques. Attempts to quantify the order and strength of the relationships in a relevance tree (Fischer, 1970) are beyond the scope of this presentation.

BIBLIOGRAPHY

Alderson, R. C., and Sproull, W. C. "Requirement Analysis, Need Forecasting, and Technology Planning Using the Honeywell Pattern Technique." *Technological Forecasting and Social Change* 3 (1972): 255-65.

Fischer, Manfred. "Toward a Mathematical Theory of Relevance Trees." *Technological Forecasting and Social Change* 1 (1970): 381-89.

Harrison, Howard. "Creative Aspects of Modeling a Complex System for Which the Model-Building Starting Point is Not Easily Determined." Department of Mechanical Engineering, University of Wisconsin, Madison, 1972.

Thesen, A. "Some Notes on System Models and Modelling." *International Journal of Systems Science*, 1973.

Warfield, John N. *An Assault on Complexity*. A Battelle Monograph, No. 3. Columbus, Ohio: Battelle Memorial Institute, 1973.

Warfield, John N. "On Arranging Elements of a Hierarchy in Graphic Form." *IEEE Transactions on Systems, Man, and Cybernetics* SMC-3: 2 (March 1973): 121-31.

Warfield, John N. *Structuring Complex Systems*. A Battelle Monograph, No. 4. Columbus, Ohio: Battelle Memorial Institute, 1974.

Oval Diagramming

PREREQUISITE TOOLS

Tree Diagrams (TRD, page 74).

USAGE

PURPOSE

Oval diagramming describes a problem as a set of complex relationships among system *variables* and variables in the system *environment*.

USES

An oval diagram provides an explicit statement of cause and effect relationships within a system and between the system and its environment. This diagram may be used to:

1) Examine the internal consistency of the analyst's conception of the complex relationships.

2) Communicate the analyst's understanding of causal relationships to others and to provide a graphic definition of the system.

3) Promote further study of hypothesized causes and observed effects, particularly when these represent problematic behavior.

4) Provide an input for techniques such as Computer Simulation Models (CSM, page 120) and Scenarios (SCN, page 164).

KEY DEFINITIONS

1) A *variable* is a factor used to describe a system which may change value as a function of time.

2) The *environment* of a system is the set of all factors which are salient to the understanding of systems relationships, but which are outside the influence of the system variables.

3) *Dynamic behavior* is a consequence of delayed interactions among system variables. The dynamic state of a system depends on the prior values of state variables.

SHORT DESCRIPTION

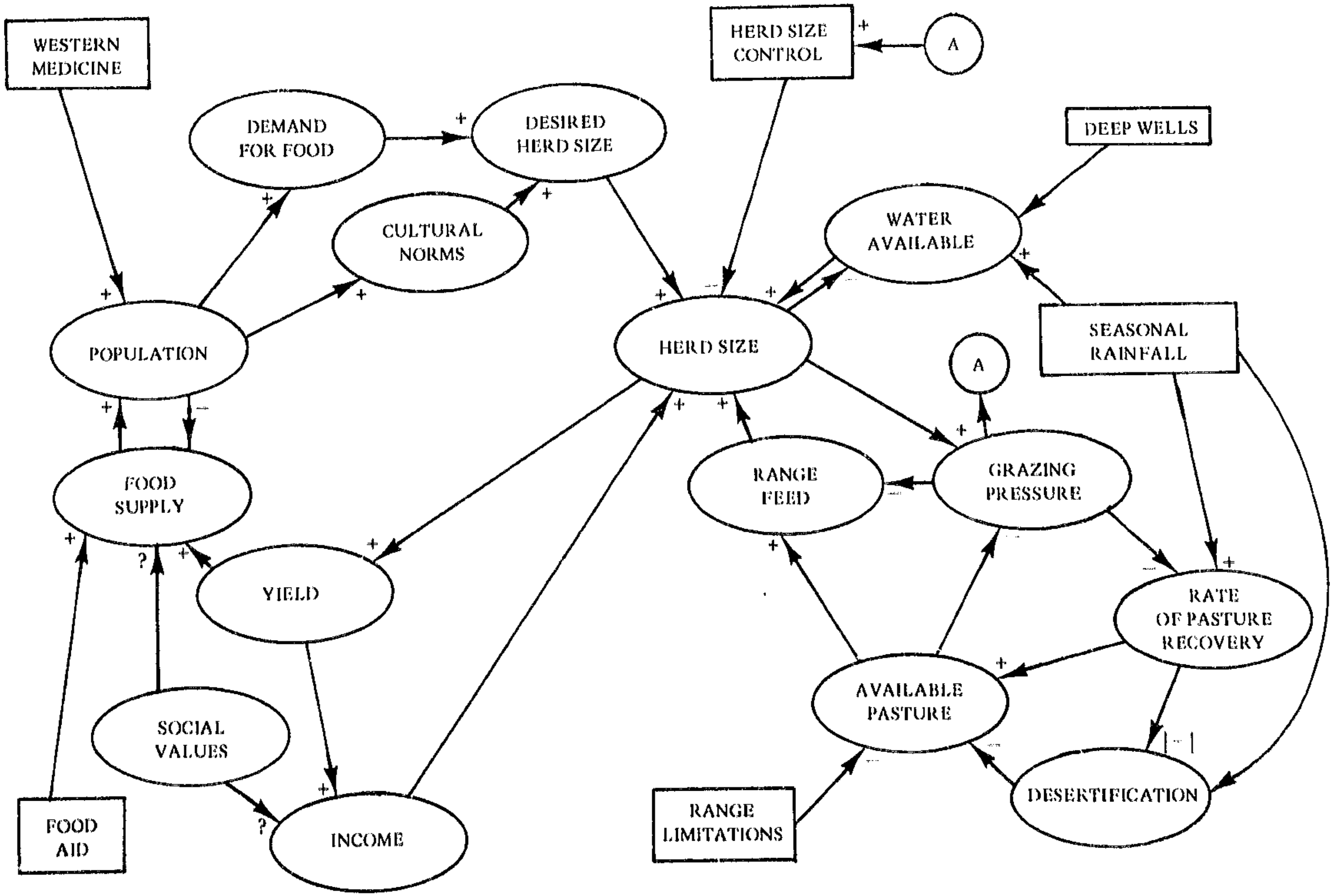
An oval diagram is a model which identifies system variables (in ovals) and the connecting arrows which link the variables together (see figure 1). The type of interaction is determined by considering the effect of a small change in one variable on the magnitude of another.

An oval diagram is constructed by drawing on the experiences, observations, and intuition of the analyst(s) in order to translate mental models into an explicit statement. This statement forms the framework for testing hypotheses, gathering additional data, or analyzing the system's *dynamic behavior*.

ADVANTAGES

1) In oval diagramming, complex causes and effects are seen as expanding sequences starting from a key variable.

FIGURE 1
Oval Diagram for Nomad Pastoralism Eco-System



2) The thought that goes into oval diagramming often uncovers relationships that may be the key to a further understanding of system behavior.

3) Oval diagrams facilitate communication between analysts and decision makers by highlighting undesirable effects and relationships that require careful attention.

4) By treating assumptions and hypotheses explicitly, oval diagrams may resolve discrepancies or deficiencies in the mental models used by decision makers.

5) The span of relevant factors is easily shown in the oval diagram so that changes in the problem scope can be accommodated by changing the diagram.

LIMITATIONS

1) Diagramming all conceivable interactions results in a complex and unwieldy diagram. On the other hand, highly aggregated models may lead to false inferences about system behavior (see DeNeufville and Stafford, 1969).

2) The validity of the oval diagram can only be inferred by relation to experience. Any hypothesized relationship may be proven false by a statistical analysis of data, but failure to do so does not validate the relationship. For example, it may be demonstrated that a relationship between NUMBER OF EXTENSION WORKERS and NUMBER OF FARMERS ENTERING A PROGRAM does *not* exist; however, no test will assure one that there is a causal relationship.

3) An oval diagram may be idiosyncratic because there is no unique representation of a complex set of relationships.

4) The selection of salient variables and relationships reflects the biases of the analyst, even though the diagrammer may attempt to incorporate shared values into the hypothesized relationships.

5) The oval diagram is a descriptive model only—the complex interaction of multiple variables and relationships can only be inferred. Other techniques are required to fully understand the behavior of the entire system (see Computer Simulation Models, CSM, page 120).

REQUIRED RESOURCES

LEVEL OF EFFORT

The level of effort required depends on the planned use for the tool.

1) If the oval diagram is a first step in complex modeling and systems analysis, then the effort will match the input requirements of the tool used in the next step.

2) If the tool output is used for communication, discussion, or training, then more effort may be spent on refining the final diagram.

3) If the tool is designed to facilitate understanding as an aid to decision making, or for clarifying issues, then more attention must be given to the development process and explicit treatment of assumptions and hypotheses.

SKILL LEVEL

The analyst must be able to see the problem and environment as a system. A System Definition Matrix (SDM, page 67) may be useful here.

When identifying variables, there is a tendency to think only in terms of system components, e.g., organizational units. Thus skills used to identify system functions (Function Expansion, FEX, page 45) and system performance measures (Logical Framework, LGF, page 260) can be useful. Oval diagramming must be learned by repeated attempts at describing complex relationships.

TIME REQUIRED

Oval diagrams may be constructed either in a short time (less than an hour) or over a longer time (e.g., the life of a project), depending on the level of detail and internal consistency desired.

DESCRIPTION OF TOOL

SUPPLEMENTAL DEFINITIONS

1) A *causal chain* is a sequence of cause and effect relationships between variables (see figure 2).

2) A *causal loop* is a causal chain which is connected so that a change in any variable eventually feeds back through the chain to affect this variable. A causal loop has a *feedback* effect (see figure 2).

3) *Mutually-causal* variables occur when a change in one variable causes a change in another which is fed back to affect the first, e.g., a causal loop involving only two variables (see figure 2).

4) *Feedback structure* is the set of relationships describing a system that involves one or more interlocking causal loops (see figure 1).

5) *Correlation* is an observed relationship between two or more variables in which the changes in one variable may be associated with predictable changes in another; the relationship, however, is not necessarily cause-effect.

6) *Logical inconsistencies* occur when hypothesized relationships among variables are inconsistent. This may result from an imprecise variable definition, faulty logic, or a confusion of correlative behavior with cause-effect relationships.

Kinds of interactions:

1) A *direct effect* is an interaction between two variables so that a change in one results in a similar change in the other, i.e., either both increase or both decrease (see figure 3).

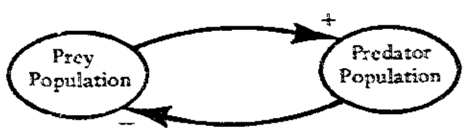
2) An *inverted effect* is an interaction between two variables so that a change in one results in an opposite change in the other, i.e., if one increases the other decreases, if one decreases the other increases (see figure 3).

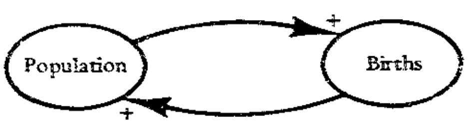
3) A *threshold effect* occurs when one variable does not change until the other variable changes significantly (see figure 4).

4) A variable interaction is *irreversible* if the variable only increases or only decreases (see figure 5).

FIGURE 2
Multiple Causal Relationships

Mutually Causal Variables





A Causal Chain

A Causal Loop: Feedback Effect

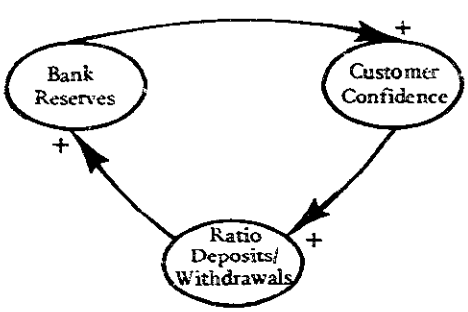


FIGURE 3
Types of Interaction Between Two Variables, A and B

	If A:	Then B:
Direct Effect	Increases	Increases
	Decreases	Decreases

EXAMPLES.

HYBRID SEED YIELDS (Variable A) influence NUMBER OF NEW ADOPTERS (Variable B)

POPULATION OF FERTILE FEMALES (Variable A) produces NUMBER OF BIRTHS (Variable B)

FERTILIZER APPLIED (Variable A) causes CROP YIELD (Variable B)

	If A:	Then B:
Inverted Effect	Increases	Decreases
	Decreases	Increases

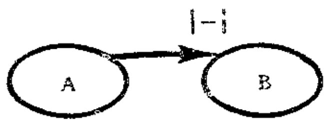
EXAMPLES:

ANTI-SMOKING ADVERTISING (Variable A) influences CIGARETTE CONSUMPTION (Variable B)

EXTENT OF FLOODING (Variable A) produces CROP YIELDS (Variable B)

CONTRACEPTIVES AVAILABLE (Variable A) causes NUMBER OF BIRTHS (Variable B)

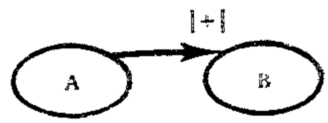
FIGURE 4
Illustration of Threshold Relationships



Inverted Threshold Effect	A must increase significantly before B decreases or A must decrease significantly before B increases

EXAMPLE:

When POLITICAL AGITATION (A) exceeds a level of tolerance, the LEVEL OF CIVIL LIBERTIES (B) is affected.

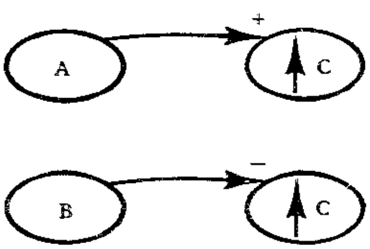


Direct Threshold Effect	A must increase significantly before B increases or A must decrease significantly before B decreases

EXAMPLE:

When COOPERATIVE MEMBERSHIP (A) exceeds a threshold number, FARMGATE PRICES (B) may be affected.

FIGURE 5
Illustration of Irreversible Effects

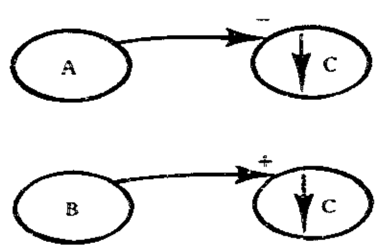


	If:	Then:
Irreversibly Increasing Variable	A increases, or B decreases	C increases
	Otherwise	C is unchanged

EXAMPLES:

Increasing PRICES (A) cause increasing WAGE DEMANDS (C)

Decreasing PASTURE RECOVERY RATE (B) causes increasing DESERTIFICATION (C)



	If:	Then:
Irreversibly Decreasing Variable	A decreases, or B increases	C decreases
	Otherwise	C is unchanged

EXAMPLES:

Increasing OIL CONSUMPTION (A) decreases (depletes) the OIL RESERVES (C)

Decreasing PRODUCT QUALITY (B) decreases (destroys) COMPANY REPUTATION (C)

REQUIRED INPUTS

Oval diagramming is most effective when the purpose is to increase understanding of a complex problem. Familiarity with the problem situation is therefore desirable, though much of the input will come from a basic understanding of relationships, e.g., the mental models that are formed from experience and observation.

When oval diagrams are constructed by a team, the members should broadly represent those concerned with the problem. More than five people working on one diagram limits effectiveness.

Tree diagrams (TRD, page 74) may be used to help identify variables. An interaction matrix diagram (IMD, page 92) is also useful for identifying the significant interactions.

TOOL OUTPUT

The output is an oval diagram which provides a graphic statement of the variables and relationships necessary to describe the system. The boundary of the system and the scope of possible interventions are defined.

The oval diagram focuses attention on the need for further information-gathering and testing of hypothesized relationships. The oval diagram provides the basic input to other techniques such as Scenarios (SCN, page 164) to gain greater understanding of system dynamic behavior.

IMPORTANT ASSUMPTIONS

Decision makers use mental models as well as more formal models to understand behavior and select choices of action. Mental models may be very complex, yet they are seldom made explicit except by inference from the actions of the decision makers. Oval diagramming depends on the ability of analysts (and decision makers) to picture the hypothesized relationships and the assumed causes and effects.

The assumed interactions between variables is identified by considering small changes in the causal variable. Relationships often change character when large magnitude variations occur, but an examination of this behavior is outside the province of this technique.

The oval diagram represents a definition of the system that is distinct from the environment. Setting a boundary between the system and its environment assumes a hierarchical relationship between systems and the larger systems which contain them. Hence, any environmental variable is part of an expanding systems hierarchy (see Tree Diagrams, TRD, page 74).

METHOD OF USE

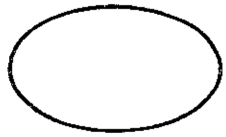
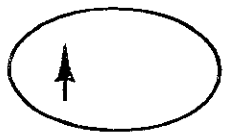
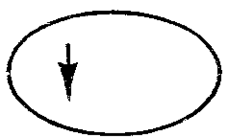
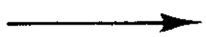
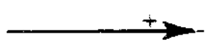
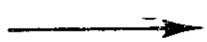
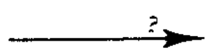
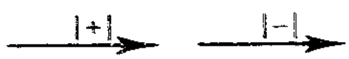
GENERAL PROCEDURE

Oval diagramming is essentially a trial and error process. Therefore it is important to start diagramming immediately. The recommended procedure is to start* with a simple tree diagram (TRD, page 74) and when many factors keep reoccurring in different branches of the tree, to switch to an oval diagram.

1. **Construct a tree diagram of the system.**
   - 1.1 Identify variables for an influence tree.
   - 1.2 Select a starting variable which describes the condition or symptom of the problem in neutral terms.
   - 1.3 Construct the tree branches after each variable by identifying the variables which influence (or produce or cause) this variable to change value.
2. **Convert the influence tree to oval diagram form.**
   - 2.1 Locate the starting variable in the center.
   - 2.2 Cluster the influencing variables around it.
   - 2.3 Indicate the branching relationships as arrows between ovals.
   - 2.4 Form *causal chains* of variables.
   - 2.5 Do not repeat variables on the diagram. Form causal loops back to previously shown variables.
3. **Identify the types of interactions between variables.**
   - 3.1 Isolate two variables and imagine the effect that a small increase in the causal variable will have on the affected variable, assuming that all other factors do not change.
   - 3.2 Indicate whether the relationship is a *direct* or *inverted effect* (see figure 3).
   - 3.3 Indicate if a *threshold effect* is hypothesized (see figure 4).
   - 3.4 Indicate if the variable interaction is *irreversible* (see figure 5).
4. **Identify variables outside the system.**
   - 4.1 Apply the influence tree stopping rule (TRD, page 74) to identify any factor which is outside the influence of other variables within the system.
   - 4.2 Enclose these variables in a box to distinguish them from system variables (optional).
5. **Review the diagram for consistency.**
   - 5.1 See if the variables reflect a similar level of detail/aggregation.

*Oval diagrams may be constructed from Interaction Matrices (see IMD, page 92), but this emphasizes identifying all variables first, then determining the relationships.

FIGURE 6
Summary of Symbols and Notation for Oval Diagramming

SYMBOL	MEANING
	VARIABLE
	EXOGENOUS VARIABLE
	VARIABLE WHICH ONLY INCREASES
	VARIABLE WHICH ONLY DECREASES
	DIRECTION OF CAUSALITY
	DIRECT EFFECT
	INVERTED EFFECT
	NATURE OF INTERACTION CHANGES
	NATURE OF INTERACTION UNCERTAIN
	THRESHOLD EFFECT
	BREAK IN ARROW (FOR DIAGRAM CLARITY)

5.2 Eliminate any redundant relationships.

5.3 Look for spurious *correlations*, e.g., two variables which are shown as causally related when the apparent cause and effect interaction is actually the effect of a third variable. The classic example is the correlation between FIRE TRUCKS and FIRE DAMAGE. The number of fire trucks responding to a fire does not cause the amount of damage; the size of the fire affects both variables (DeNeufville, 1969).

5.4 Test the causal chains of hypotheses by considering the radiating effect of a small change in a variable in the chain. Are the sequences of interactions consistent with the observed behavior in the system?

6. **Complete the diagram for display or analysis.**

6.1 If necessary, redraw the diagram to clarify relationships (see figure 6).

6.2 Isolate causal loops and key variables by highlighting or diagramming them separately.

EXAMPLE

The eco-system problem which was diagrammed as an influence tree (see Tree Diagrams, TRD, page 74) will be continued.

Construct a Tree Diagram of the System

The tree diagram represents factors which interact to cause the nomad population's problems in the drought-stricken Sahel. A starting variable for the diagram was selected by first stating the known condition or symptom which describes the problem: the region is overpopulated with both people and animals. The tree diagram could have been started with OVERPOPULATION OF NOMADS or OVERSIZED HERDS. However these variables are not neutral, e.g., overpopulation is only relative to available resources. Consequently, HERD SIZE was selected* because it may either increase or decrease in relation to other variables. This permits the problem to be represented as the interaction among system variables.

Repeated application of the branching rule, "Identify the variables which influence this variable," for each newly identified variable resulted in the completed diagram shown in figure 7 (see Tree Diagrams, TRD, page 74). In practice, only a partial tree is needed to start the oval diagram.

*NOMAD POPULATION would have been an equally acceptable starting variable for the tree diagram.

Convert the Influence Tree to an Oval Diagram

The starting variable was drawn in the center with the variables which influence it clustered around (see figure 8). The branches of the tree diagram became arrows between the variables which became ovals. Each branch became a causal chain, and when a variable was repeated in the tree diagram (e.g., HERD SIZE) a causal loop was formed (see figure 9, the *mutually causal-relationship* between HERD SIZE and WATER AVAILABLE).

FIGURE 7
Influence Tree Diagram Prepared to Start Oval Diagram of Nomad Pastoralism Eco-System

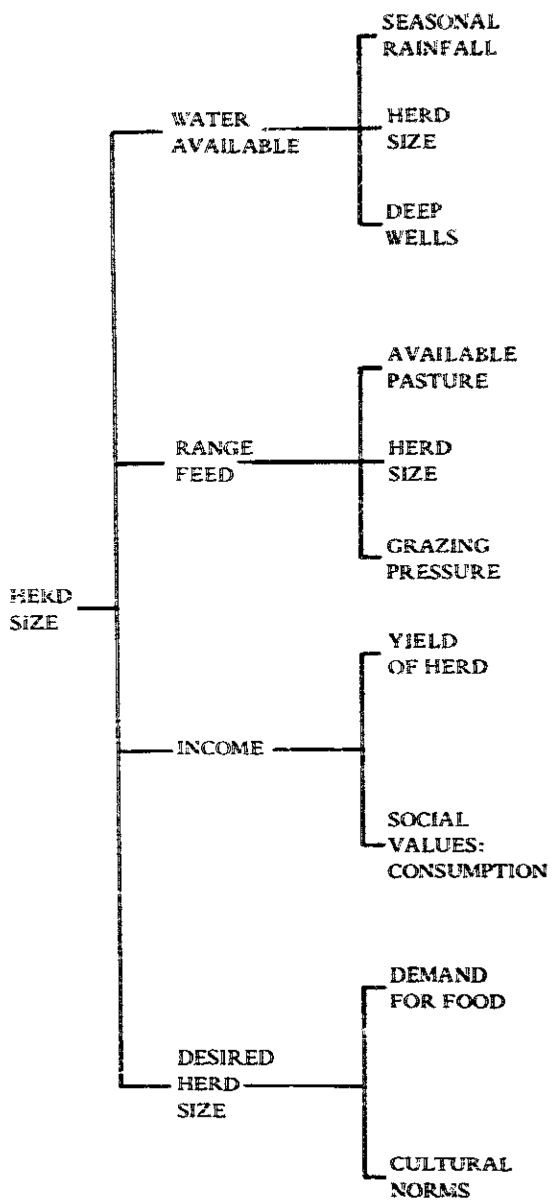
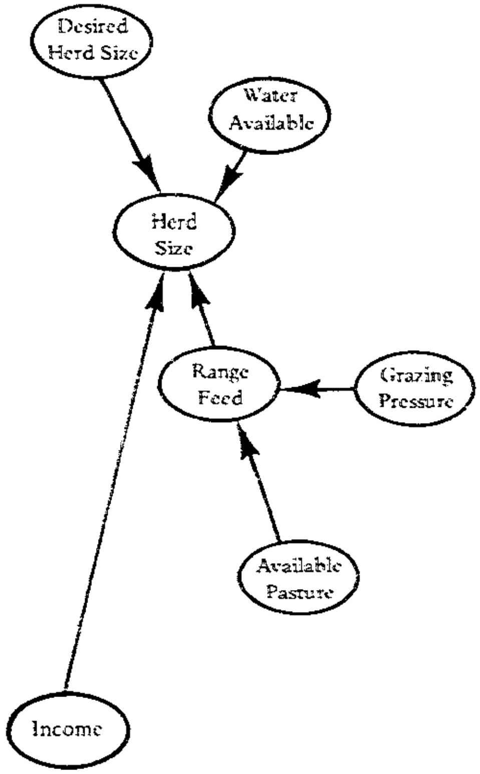


FIGURE 8
The Initial Steps in Constructing an Oval Diagram from a Tree Diagram



Identify the Types of Interactions Between Variables

If HERD SIZE were to increase by some small amount, the WATER AVAILABLE would decrease if all other factors were held constant. The – sign by the arrowhead on the relationship shown in figure 9 indicated this inverted relationship. By posing similar changes between each pair of related variables (considering only one relationship at a time), the analyst indicated on the diagram the hypothesized interaction between the variables.

One such hypothesis concerned the relationship between the RATE OF PASTURE RECOVERY and the AVAILABLE PASTURE. If the RATE increased slightly, the AVAILABLE PASTURE was directly affected. If the rate decreased below some threshold value, the relationship became distorted (DESERTIFICATION increased irreversibly, which decreased the AVAILABLE PASTURE). These hypotheses were noted on the oval diagram using the symbols shown in figure 9.

Identify Variables Outside the System

The SEASONAL RAINFALL was shown as a variable* which was outside the system. Although this variable produced the WATER AVAILABLE and influenced the RATE OF PASTURE RECOVERY, nothing within the system diagram was hypothesized to influence the SEASONAL RAINFALL.

Other factors were added to the oval diagram (see figure 1) to show the effects of external interventions on the system, e.g., digging DEEP WELLS or imposing RANGE LIMITATIONS and HERD CONTROL on the nomads by government interference. Each of these actions were determined by levels of variables within the system and could also be shown on the diagram** (e.g., the relationship between GRAZING PRESSURE and HERD SIZE CONTROL).

Review the Diagram for Consistency

One of the biggest problems in oval diagramming is to show widely varying levels of detail (disaggregated variables). In this example, all nomads and all livestock were aggregated into just two variables: POPULATION and HERD SIZE. The oval diagram could be restructured to show regional variables or tribal groups, but this detailing should follow a first attempt at a more general model.

A redundant relationship was shown initially in the oval diagram between HERD SIZE and RANGE FEED (compare figure 9 with figure 1). GRAZING PRESSURE was defined to link HERD SIZE with RATE OF PASTURE RECOVERY. When reviewing the diagram, it was observed that the effect of HERD SIZE on RANGE FEED was accounted for by the linkage through GRAZING PRESSURE.

Social value relationships were shown rather ambiguously on the diagram. A relationship between DESIRED HERD SIZE and NOMAD POPULATION was hypothesized to include not only the DEMAND FOR FOOD but a set of CULTURAL NORMS. The norm may be a tradition that X cattle are desired for Y family members. Such a hypothesis requires that information be gathered for further study.

SOCIAL VALUES : CONSUMPTION influence how the YIELD from the HERD was to be taken—either to effect FOOD SUPPLY or to produce INCOME from milk or beef sales. The INCOME may be applied to further build up the HERD SIZE. By constructing these narratives, the hypothesized relationships represented in the oval diagram were systematically examined. It is important, however, to consider both increases and decreases in key variables.

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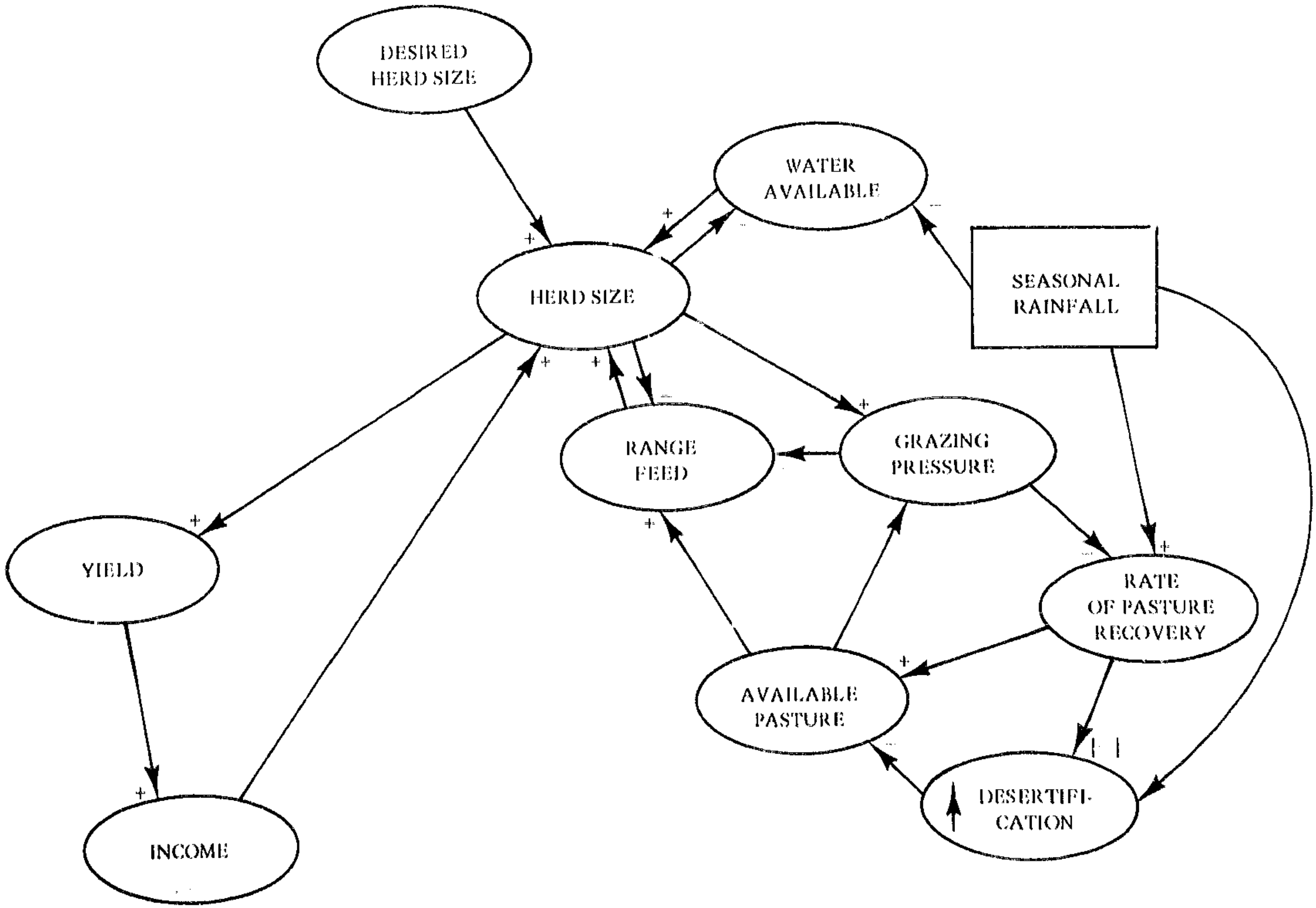
*It would have been an error to depict DROUGHT as a variable since this is just a very low level of the neutral variable, SEASONAL RAINFALL.

**The relationships between outside interventions and system variables are described further in the continuation of this example in Interaction Matrix Diagrams (IMD, page 92).

FIGURE 9
Oval Diagram Depicting Causal Loops in Nomad Pastoralism Eco-System



Complete the Diagram for Display or Analysis

There were a number of interacting causal loops which led to the problems of the nomads. Each of these loops could be isolated for further analysis and perhaps programmed on a computer simulation model (CSM, page 120) (Picardi, 1974). For purposes of presentation to decision makers, it is desirable to isolate these major effects by redrawing the diagram or highlighting the relationships involved. Transparent overlays are effective in constructing the model before an audience. Color-coding and geometric shapes (other than ovals) are also effective in clarifying the complex causal hypotheses.

At the very least, this example illustrates the kinds of interactions which help to orient efficient information-gathering for detailed analysis and design.

THEORY

Oval diagramming, or causal modeling, draws from many disciplines including economics, sociology, business, and engineering. DeNeufville and Stafford (1969) describe the use of "arrow diagrams" to model the causal relationships between variables. The field of Systems Dynamics (Forrester, 1968) stems from efforts to model the complex relationships which lead to problematic behavior in industrial organizations. The MIT group subsequently attempted to model cities (Forrester, 1969) and the world (Meadows, 1972).

While these efforts were mainly concerned with developing a computer simulation model to test hypotheses and demonstrate the probable consequences of different policies, each must start with a causal model or oval diagram of the relationships to be tested.

The work of Harrison (1972) and Abraham (1975) is particularly noteworthy in their attempts to translate complex techniques into straightforward models of problematic system behavior.

A second approach concentrates on identifying the structure of interactions (see Interaction Matrix Diagrams, IMD, page 92). Interpretive Structural Modeling (Warfield, April, September, 1973; 1974) relies on computer assistance to manipulate the matrices of relationships into a model. An interaction matrix has a direct correspondence to an oval diagram and provides a powerful technique for automatically analyzing large numbers of complex interactions. Gerardin (1973) describes an application of the technique to planning, and at a recent conference (IEEE Conference, 1976) several authors applied the technique to development problems.

BIBLIOGRAPHY

Abraham, Stanley. "How to Appreciate Using a Structure of Feedback Loops: A Set of Instructions." WP 13-75. Graduate School of Management, UCLA, February 1975.

Baldwin, Maynard M., ed. *Portraits of Complexity: Applications of Systems Methodologies to Societal Problems.* Battelle Monograph, No. 9. Columbus, Ohio: Batelle Memorial Institute, June 1975.

DeNeufville, R., and Stafford, J. *Systems Analysis for Engineers and Managers.* New York: McGraw-Hill, 1969.

Forrester, Jay W. *System Dynamics.* Cambridge, Mass.: MIT Press, 1968.

Forrester, Jay W. *Urban Dynamics.* Cambridge, Mass.: MIT Press, 1969.

Gerardin, Lucien A. "Systems Approaches to Developing Countries." Proceedings of the Symposium sponsored by IFAC and IFORS, Algiers, Algeria, May 28-31, 1973.

Gordon, Geoffrey. *System Simulation.* Englewood Cliffs, N.J.: Prentice-Hall, 1969.

Harrison, H.L. "Creative Aspects of Modeling a Complex System for Which the Creative Model-Building Starting Point is Not Easily Determined." Department of Mechanical Engineering, University of Wisconsin, 1972.

Meadows, D. H., et al. *The Limits of Growth.* New York: Universe Books, 1972.

Picardi, Anthony C. "A Systems Analysis of Pastoralism in the West African Sahel." Annex 5 of *A Framework for Evaluating Long Term Strategies for the Development of the Sahel-Sudan Region.* Center for Policy Alternatives, M.I.T., December 31, 1974.

Proceedings of 1976 IEEE Conference on Cybernetics and Society. Washington, D.C.: IEEE, 1976.

Warfield, John N. *An Assault on Complexity.* A Battelle Monograph, No. 3. Columbus, Ohio: Battelle Memorial Institute. April 1973.

Warfield, John N. "Binary Matrices in System Modeling." *IEEE Transactions on Systems, Man, and Cybernetics.* Vol. SMC-3, No. 5, September 1973, pp. 441-49.

Warfield, John N. *Structuring Complex Systems.* A Battelle Monograph, No. 4. Columbus, Ohio: Battelle Memorial Institute, 1974.

Interaction Matrix Diagramming

PREREQUISITE TOOLS

Tree Diagrams (TRD, page 74) and Oval Diagramming (OVD, page 81).

USAGE

PURPOSE

Interaction matrix diagrams describe complex relationships by identifying self-interactions within members of a set and cross-interactions between members of different sets of elements.

USES

Interaction matrices may be used singly or in combination to:

1) Identify the elements (e.g., objectives, constraints, or system variables relevant to the description of a problem, project, or system).

2) Systematically explore the possible interactions within a set of elements, using a *self-interaction matrix*.

3) Indicate the existence, strength, importance, or direction of an interaction between any two elements.

4) Identify the interactions between two different sets of factors, e.g., between project objectives and activities.

5) Provide a matrix checklist for record keeping, communication, and planning.

KEY DEFINITIONS

1) A *matrix* is a mathematical and graphical representation in two dimensions.

2) A *self-interaction matrix* represents relationships within a single set of variables.

3) A *cross-interaction matrix* represents relationships between dissimilar sets of variables.

4) A *reduced matrix* is formed by omitting one or more rows or columns from the original matrix.

5) A *set* is a collection of elements having some common property.

6) A *matrix entry* is the symbol used to indicate the existence or absence of a relationship between the element in the row and the element in the column (which together define the entry).

SHORT DESCRIPTION

Interaction matrices provide a technique for first identifying the members of a *set* of elements, e.g., the objectives for a project, and then systematically examining all the possible interactions among members of the set. If the factors can be categorized, the cross-interactions between members of different categories can be determined (see figure 1). A *matrix entry* may show a range of information, including whether the relationship between the two *elements* has been hypothetically or empirically determined, or whether the relationship is or would be desirable if it were established. The matrix entry may also show the relative strength or importance of the interaction. Interaction matrices correspond directly to tree diagrams (TRD, page 74) and oval diagrams (OVD, page 81).

ADVANTAGES

1) All factors relevant to the description of a problem or system are identified in a separate exercise prior to specifying interactions.

2) All possible interactions between elements are examined in a systematic procedure which minimizes omissions and tests for inconsistencies.

3) The existence of a relationship is determined without having to further specify the type or degree of interaction.

4) A large number of variables may be analyzed without significantly affecting the clarity or utility.

5) The matrix provides a convenient means of recording information and tasks for further study.

6) The procedure lends itself to a multi-disciplinary approach.

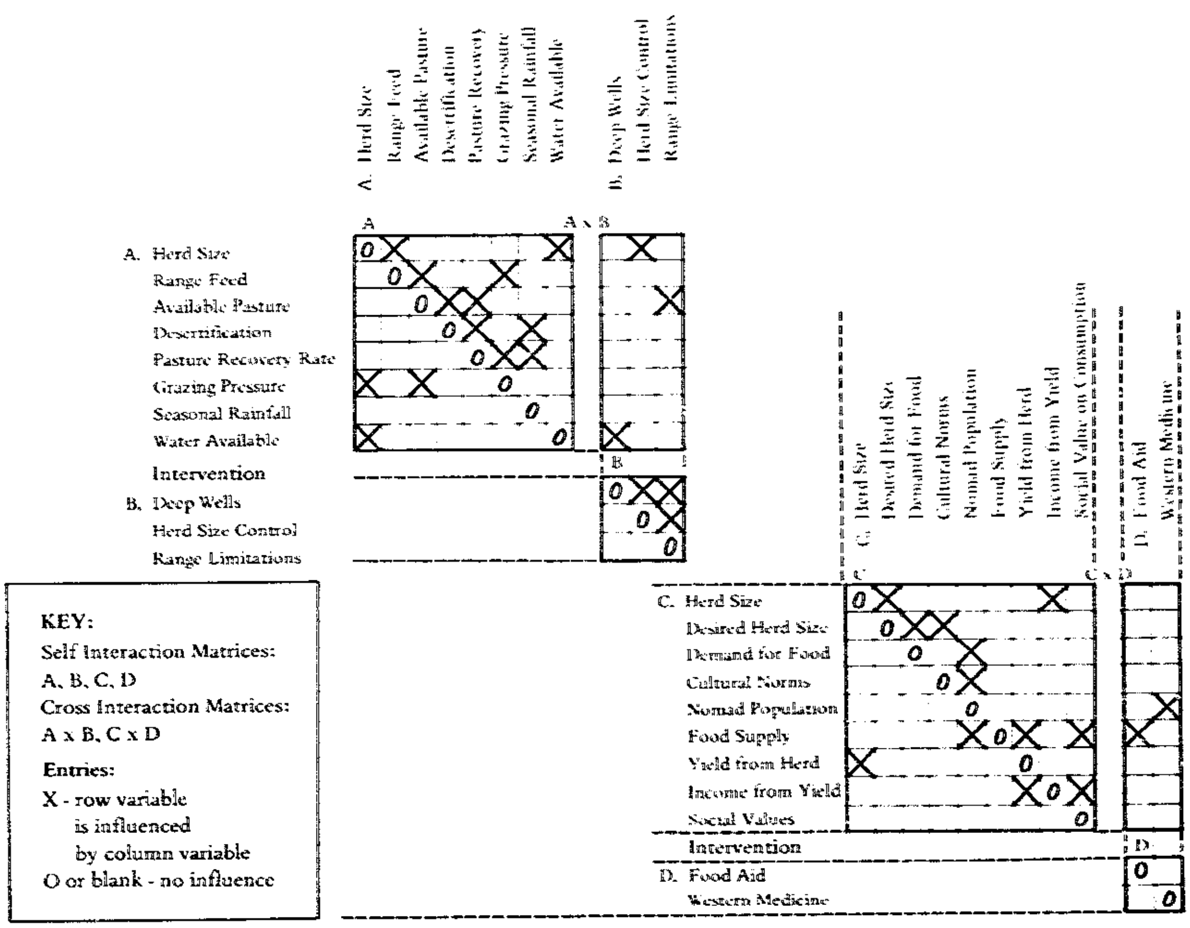
LIMITATIONS

1) Separating the tasks of generating elements and identifying relationships may run counter to thought processes, e.g., tracing cause-effect chains or the order of preference among descriptive elements. In these processes, new elements often emerge as relationships are examined (see Tree Diagrams, TRD, page 74).

2) The number of relationships to be examined increases as the square of the number of matrix elements, e.g., there are nine possible interaction pairs among three elements.* Fortunately, not all interactions need to be examined, but the process can be time-consuming.

*This assumes that the interaction of an element with itself must be examined.

FIGURE 1
Interaction Matrix Diagram Derived from Oval Diagram of Nomad Pastoralism Relationships



3) Tracing cyclical relationships and other linkages through the matrix structure can be confusing. An oval or tree diagram provides greater clarity than the matrix format.

REQUIRED RESOURCES

LEVEL OF EFFORT

Construction of interaction matrix diagrams requires two distinct tasks: identifying relevant elements, and analyzing interactions among them. The first task may exploit the collective judgment of a large group using brainstorming (BSG, page 3) or the Nominal Group Technique (NGT, page 14). Secondary information sources may also be used to develop the list.

The task of identifying relationships requires considerable effort and expertise. This may be a team task if care is taken to explain the elements and the relationship which is to be examined.

SKILL LEVEL

Some skill is required to diagram the interaction matrices in order to preserve clarity, and to interpret the linkages between elements.

TIME REQUIRED

The construction of an interaction matrix for a relatively small number of factors may take hours, depending on one's ability to assess the matrix entries and the amount of information included.

SPECIAL REQUIREMENTS

Interaction matrix diagrams may be constructed using special computer programs. This greatly facilitates the systematic analysis of many elements and permits quick and accurate performance of matrix operations (Warfield, 1974).

DESCRIPTION OF TOOL

SUPPLEMENTAL DEFINITIONS

1) A *transitive relationship* requires that a directed relationship among three or more elements be consistent, e.g., if A is preferred to B, and if B is preferred to C, then A must be preferred to C (see figure 2).

2) A *directed relationship* specifies that the existence of the relationship is dependent on the order in which the two elements are considered, e.g., "is influenced by," "is preferred to," and "is subordinate to."

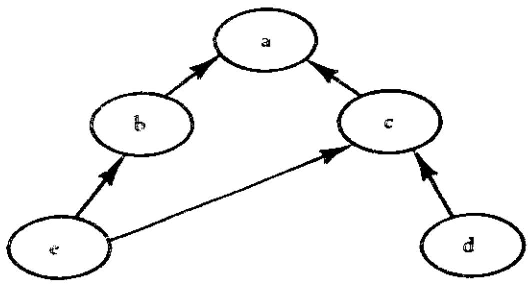
FIGURE 2
Properties of Relationships

Self-Interaction Matrix of Relationship R

	a	b	c	d	e
a	0	0	0	0	0
b	1	0	0	0	0
c	1	0	0	0	0
d	0	0	1	0	0
e	0	1	1	0	0

NOTE: "1" means that row element *i* is related to column element *j*. "0" means that relationship *R* does not apply between the elements.

Oval Diagram of Matrix Assuming a Directed, Intransitive, Asymmetrical and Irreflexive Relationship *R*



SYMBOL DEFINITIONS:
a, b, c, d, and e are elements of a set.
i, j are any two elements.
R denotes a relationship between any two elements, a R b signifies that element *a* is related to element *b* by the relationship R.

MATRIX RELATIONSHIP PROPERTIES
Reflexivity. A relationship is reflexive if a R a, b R b, . . ., i R i. If not, the relationship is *irreflexive* because all the diagonal elements are "0."
Symmetry. A relationship between two elements is symmetrical if when i R j, then j R i. For example, Group A "communicates with (R)" Group B. In this case, the two halves of the matrix are symmetrical about the diagonal. If not, then the relationship is *assymetrical*.
Transitivity. A relationship is transitive if when a R b and b R d then a R d. For example, project A "is preferred to (R)" project B which is preferred to Project D, therefore Project A must be preferred to Project D. If not, the relationship is *intransitive*. The entries at column *a* of rows *b* and *e* are different, indicating an intransitive relationship (or an inconsistent matrix entry).

3) A *reflexive relationship* occurs when the variable interacts with itself (see figure 2).

4) A *symmetrical relationship* means that the relationship between two elements is non-directed, i.e., the elements interact independent of the order in which they are considered (see figure 2).

5) *Linearly linked matrices* have a common set of rows or columns.

6) *Orthogonally linked matrices* have the same set of elements in the rows of one matrix and the columns of the other matrix.

REQUIRED INPUTS

If the interaction matrix diagram is to be a group effort, team members should be familiar with the problem or project. They should have diverse backgrounds in order to provide a broad perspective on relevant elements and possible relationships.

TOOL OUTPUT

The interaction matrix diagram provides a useful model, but may also be an intermediate product which is used to guide further information-gathering and study.

IMPORTANT ASSUMPTIONS

The diagramming process represents a mapping of an internal mental model to an explicit format (matrices). The technique systematizes the mapping process by examining only one pair of elements at a time. This may result in a relationship between two elements which is inconsistent with the interaction of each element to other elements (e.g., a *transitive relationship* among elements is violated). In this case, it must be assumed that the mental model is incorrect, though a cognitively complex view of the relationship may be the source of the discrepancy.

METHOD OF USE

GENERAL PROCEDURE

Throughout the following procedure, remember that interaction matrices are constructed by simply making an entry at the intersection of a row and column which indicates whether there is a specified relationship between the corresponding elements.

1. **Specify the type of elements and the relationship.**
   - 1.1 Specify if the element set is objectives, constraints, agencies, needs, variables, interventions, etc.
   - 1.2 Specify if the relationship is directed or non-directed, e.g., non-directed relationships include "is associated with," "communicates with," and "interacts with."
   - 1.3 If the relationship is directed, i.e., from one element to the other, then specify if the relationship is transitive or intransitive (see definitions in figure 2).
   - 1.4 Specify if the relationship is *reflexive* or not (see figure 2).

2. **Generate a list of elements for each set.**
   - 2.1 Ask the question: What elements are necessary to describe the (type of element) for the (context)? For example, "What elements are necessary to describe the objectives of an integrated rural development project?"
   - 2.2 Combine individual answers to this question if a group process is used, e.g., brainstorming (BSG, page 3), Nominal Group Technique (NGT, page 14), or Delphi (DLP, page 168).

3. **Construct the interaction matrices.**
   - 3.1 List all the elements of one type in the rows of a matrix.
   - 3.2 Prepare a self-interaction matrix by repeating this list of elements as the columns of the matrix to form a square (see figure 1).
   - 3.3 Prepare a cross-interaction matrix by listing elements from a different set in the columns of the matrix to form a rectangular matrix (see figure 1).

4. **Determine matrix entries.**
   - 4.1 Specify the symbol for a positive entry to indicate the existence of a relationship, e.g., "/," "X," or "1" (see also figure 1).
   - 4.2 Specify the symbol which indicates that there is no interaction between two variables (e.g., "0" or blank).
   - 4.3 Beginning with the first row of the matrix, apply the relationship test to the row element and each column element. Test by asking: Is (element *i*) (relationship) (element *j*)? For example, "Is Project A *preferred* to Project B?" or "Is variable X *influenced* by variable Y?"
   - 4.4 If the answer to the relationship test is positive, then the corresponding matrix entry is the positive symbol specified in step 4.1. If not, either enter "0" or make no entry.
   - 4.5 If a group process is used to examine each relationship, use a majority vote or group consensus to answer the relationship test.

4.6 Repeat this test for the entries in the remaining matrix rows until all possible matrix entries have been determined.

5. Examine the matrix for consistency.
   5.1 If the relationship is reflexive, confirm that the diagonal entries are positive (see example, figure 2).
   5.2 If the relationship is irreflexive, the diagonal entries should be zero.
   5.3 If the relationship is symmetrical (e.g., a nondirected relationship such as "is associated with"), then confirm that each positive row i-column j entry in a self-interaction matrix has a corresponding row j-column i entry which is positive. Otherwise, the matrix entry is inconsistent (see example, figure 2).
   5.4 If the relationship is directed and transitive, follow the iterative procedure shown in figure 3 to test whether an intransitive relationship has been erroneously entered in the matrix. For example, assume that the matrix in figure 2 describes a relationship between elements which is transitive, e.g., element i is subordinate to element j. Comparing the positive entries in the bottom row (e) with the positive entries in row b (step 7 in the test sequence) indicates that the column a entries are inconsistent. If e is subordinate to b, and if b is subordinate to a, then e must be subordinate to a or the relationships would be intransitive.

6. Specify the relative degree that the relationship applies (optional).
   6.1 Determine a scale to indicate the degree of interaction (e.g., 0 to 10, or 0 to 3) (see Rating Scales, RTS, page 29).
   6.2 For each row, assign a scale value to the entries which indicates a relationship. The value determined should reflect the relative degree to which the relationship applies compared to the other relationships in that row, e.g., the strength of interaction between the two variable elements (see example on page 99).

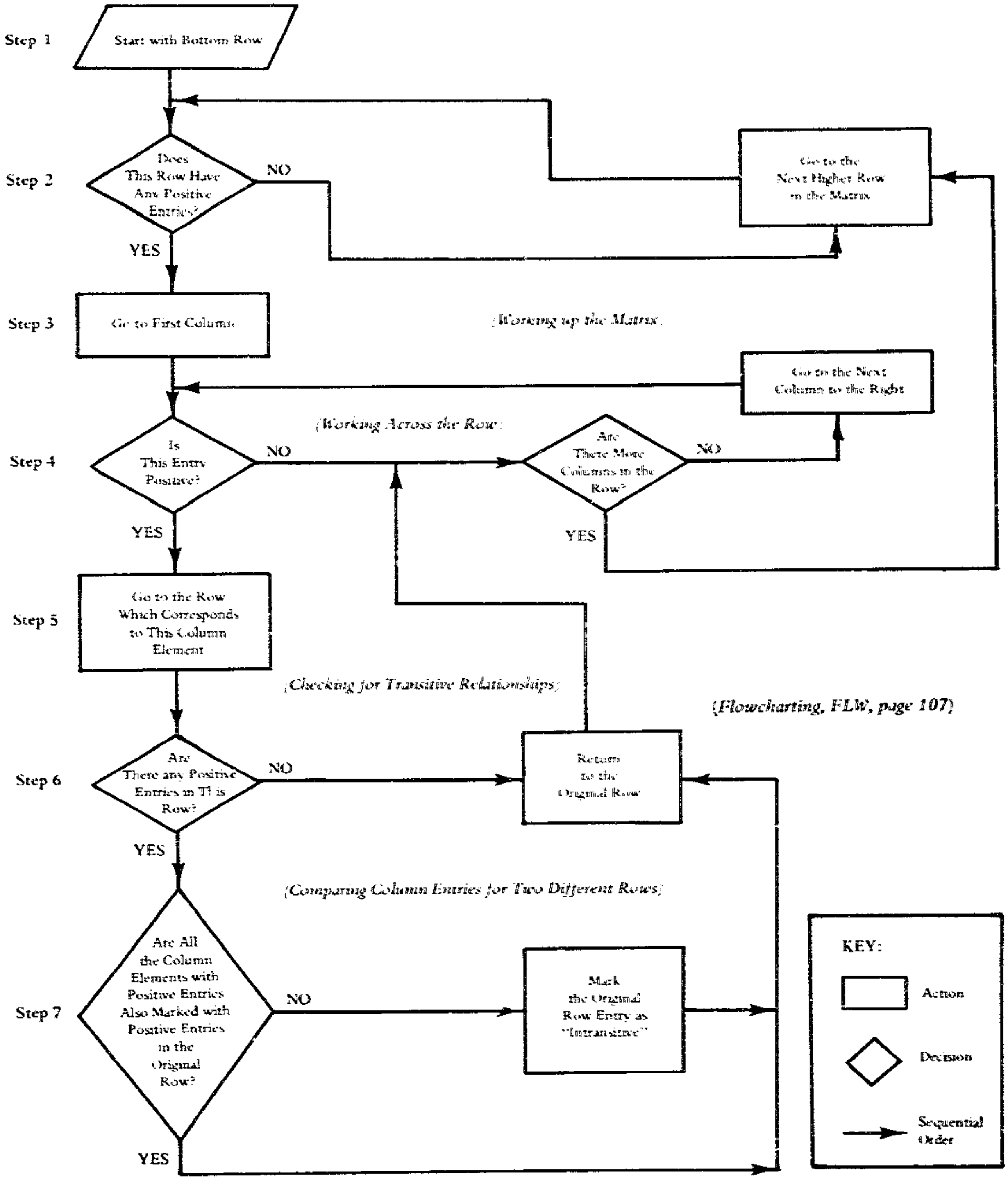
7. Construct a reduced matrix (optional).
   7.1 Eliminate any elements from a cross-interaction matrix which have no positive relationships with elements in the other set by striking the row or column from the matrix.
   7.2 Eliminate any element in a self-interaction matrix only if it has no positive row *and* column entries, e.g., it does not interact with any other element within the set.
   7.3 Eliminate any element where the degree of relationship is shown as an entry if none of the entries for that element are above a specified scale value (see example on page 99).

8. Construct an interaction matrix diagram (optional).
   8.1 Two interaction matrices may be linked together by repeating one or more elements of one set in both matrices (see HERD SIZE in matrices A and C in figure 1).
   8.2 Matrices may be linked together by alternating cross- and self-interaction matrices (see figure 1) to form *linearly linked matrices* or *orthogonally linked matrices*. For the latter, the self-interaction matrix becomes a pivot point between two cross-interaction matrices.

9. Clarify the interaction matrix by constructing a tree diagram (optional).
   9.1 Select a row of the matrix as the starting element of the tree (see Tree Diagrams, TRD, page 74).
   9.2 Branch the tree at each positive column entry. The element on the branch corresponds to the column element.
   9.3 For each of these elements the process may be repeated by branching at the positive entries on their respective rows. For the matrix in figure 2, a tree started with the element e would first branch to elements b and c, each of which would branch to element a. The branching rule in this procedure is simply the interaction matrix relationship, e.g., identify all the elements to which this element is subordinate.
   9.4 To tree diagram the converse of the relationship, repeat the above procedure, but branch in each case at the positive entries in the *column* of the element. The branching rule then becomes in effect flipped around, e.g., identify all the elements which are subordinate to this element. The oval diagram in figure 2 resembles such a tree structure, except that element e is not shown twice.

10. Clarify the interaction matrix by constructing an oval diagram (optional).
   10.1 Select the row element with the most positive entries as the starting element.
   10.2 Cluster all the elements which have positive column entries about the starting element.
   10.3 Draw lines which correspond to the relationship between each of the elements of a positive matrix entry.

FIGURE 3
Examining an Interaction Matrix for Intransitive Relationships



(Flowcharting, FLW, page 107)

FIGURE 4
Reduced Cross-Interaction Matrix for Environmental Assessment

Existing environmental characteristics or conditions \ Actions which can impact environment	A.e Alteration of ground cover	A.f Alteration of drainage	B.b Industrial sites and buildings	B.r Cuts and fills	D.e Energy generation	H.h Cooling water discharge
A.2d Water quality				4/4		
A.2e Water temperature						5/2
A.4b Erosion		5/3		4/2		
A.4c Deposition				4/1		
B.1a Trees				4/2		
C.1a Wilderness and open spaces	3/2		4/4	4/4		
C.3b Wilderness qualities	3/2		4/4	4/4		
C.ef Parks and reserves	6/4		6/4			
C.3h Rare and unique ecosystem			4/10			
C.5b Transportation network					6/3	
C.5c Utility network					2/4	

KEY:

6/4 — 6: Relative magnitude of the interaction on a scale of 1 to 10
4: Relative significance of the interaction on a scale of 1 to 10

SOURCE: Agency for International Development. *Environmental Assessment Guidelines Manual.* Washington, D.C.: USAID, September 1974.

10.4 If the relationship is directed, e.g., "*a* is preferred to *b*," locate the arrowhead at the end of the linkage in a way consistent with the meaning of the relationship. For example, the oval diagram for the matrix in figure 2 places the arrowhead at the oval surrounding the element which is second in the relationship "*b* is subordinate to *a*."

10.5 Add remaining elements and links to the diagram where each link corresponds to a positive entry on the matrix.

10.6 If the relationship is symmetrical, only the positive entries on one side of the matrix diagonal need to be diagrammed.

10.7 If the relationship is reflexive, an arrow may be shown emitting from the oval and looping back to it, though such links are often omitted.

10.8 If the relationship is transitive, the matrix will contain a number of entries which represent redundant links on an oval diagram. These may be omitted as shown in the link arrows from *e* to *a* and *d* to *a* in figure 2.

10.9 An intransitive relationship may be oval diagrammed as a feedback loop, e.g., the relationship "is affected by."

10.10 Confirm that the diagram is complete by counting the number of connecting arrows, any omitted reflexive loops, and any omitted redundant intransitive links. The total should equal the number of positive matrix entries.

10.11 The information on degree of relationship may be transferred to the oval diagram by associating the scale number with the connecting arrow (e.g., either adjacent to the arrowhead or on a box on the arrow).

EXAMPLES

Constructing a Reduced Cross-Interaction Matrix

A set of existing environmental characteristics or conditions, such as water quality and erosion, were identified and listed by various categories to reflect the environmental concerns of donor-funded development projects (*Environmental Assessment Guidelines Manual*, 1974). A second set of actions which can influence the environment were also identified by using several categories of actions. These included "alteration of ground cover," energy generation," etc.

A sample environmental assessment was then conducted by constructing a cross-interaction matrix which listed the environmental characteristics as rows and the actions as columns (see figure 4). Matrix entries were scaled from 1 to 10 (see Rating Scales, RTS, page 29). The first entry for each combination of condition was determined by an assessment of the relative strength of the interaction. This was done for every probable combination. A second entry assessed the relative significance of the interaction. Finally, a reduced cross-interaction matrix was formed by eliminating the rows and columns. The reduced matrix contained only those elements whose interaction had a strength or significance greater than 2 on the relative scale.

This matrix pinpointed the probable areas where project actions may have either a strong or significant environmental impact.

An Interaction Matrix Diagram of the Nomad Pastoralism Eco-System

The problems of the nomads in the drought-stricken Sahel were represented as a tree diagram (TRD, page 74) and an oval diagram (OVD, page 81). The oval diagram showed the relationships among a set of variables which described the nomad pastoralist eco-system, and key economic and social variables such as the SOCIAL VALUE ON CONSUMPTION (see figure 5). Self-interaction matrices were constructed for the two parts of this diagram: the livestock-environmental and the population-socioeconomic variables (see figure 1, matrices A and C). In each case, the outside interventions (shown as boxed variables in figure 5) were diagrammed as separate matrices (B and D).

The interaction matrix diagram provides a systematic way of examining the multiple interactions between an outside intervention and the internal system variables.

The cross-interaction matrices AXB and CXD were constructed to determine which system variables were influenced by the outside interventions (see figure 1). As the oval diagram indicates (figure 5), these interventions were originally diagrammed as affecting only a single system variable.

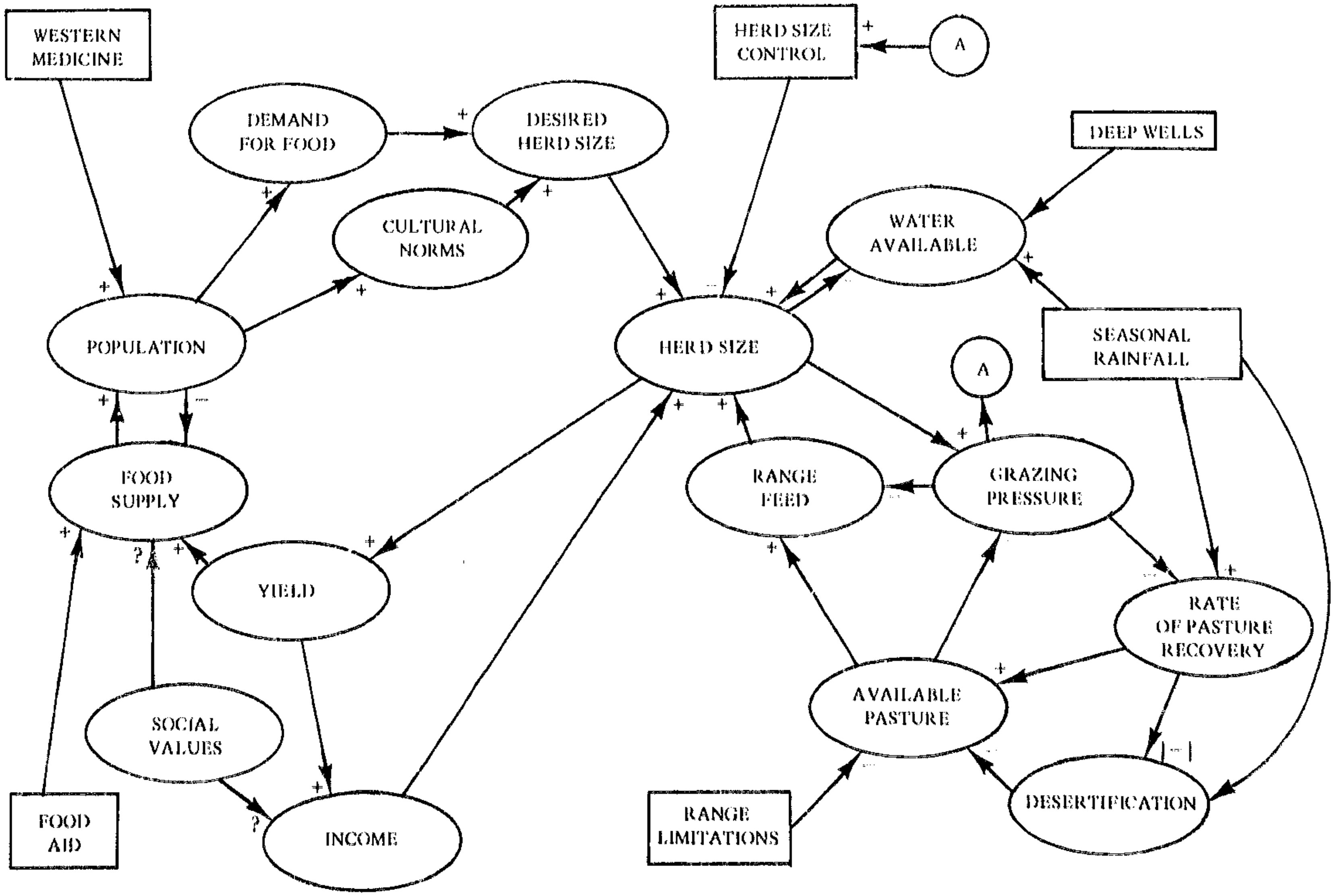
The cross-interaction matrix AXB was further specified by starting with the column DEEP WELLS and asking, for each row variable: Does this intervention (digging deep wells) influence this variable? Additional positive entries are shown in figure 6 as slashes in the cross-interaction matrix.

In order to determine the possible influence of system variables on the intervention (i.e., *mutual-causal relationships*—see OVD, page 81) the BXA and DXC cross-interaction matrices* were constructed, and the entries for each row element (intervention) were determined by

*Note that AXB and BXA are orthogonally linked matrices while BXA and BXC are linearly linked matrices.

FIGURE 5

Oval Diagram for Nomad Pastoralism Eco-System



the relationship test: Does this column variable influence this row intervention in the system? Positive responses are shown as slashes entered on the diagram (see figure 6).

Subjecting the diagram to this systematic process revealed some omissions in the original conception of the complex eco-system relationships. For example, HERD SIZE CONTROL affected a number of other variables besides the HERD SIZE. One in particular which should not have been slighted is the necessity to influence the DESIRED HERD SIZE variable of the nomad pastoralist decision maker. Also, the crucial interaction between HERD SIZE CONTROL and RANGE LIMITATIONS is pinpointed. Other interventions such as VETERINARY SERVICES can be added to examine further interactions.

The oval diagram may then have been redrawn to form the interaction matrix diagram to show these additional hypothesized relationships.

Constructing a Tree Diagram to Clarify Relationships

Multiple relationships may be lost in the complexity of the matrix format. A simple way to clarify the diagram is to construct a tree diagram (TRD, page 74) of the interactions. A tree diagram is shown for the relationships of HERD SIZE CONTROL to other elements of the description (see figure 7). The right-hand tree lists the factors which influence the intervention of HERD SIZE CONTROL. The right-hand branches represent the positive entries in the column labeled HERD SIZE CONTROL. The left side describes variables which are influenced by this intervention. The left-hand branches are the entries in the row with the same label.

Some items are duplicated on both lists, indicating that attempting to control HERD SIZE is a complex process involving feedback of variables such as HERD SIZE and GRAZING PRESSURE on range lands.

FIGURE 6
Revised Interaction Matrix Diagram Showing Influences on Interventions in System

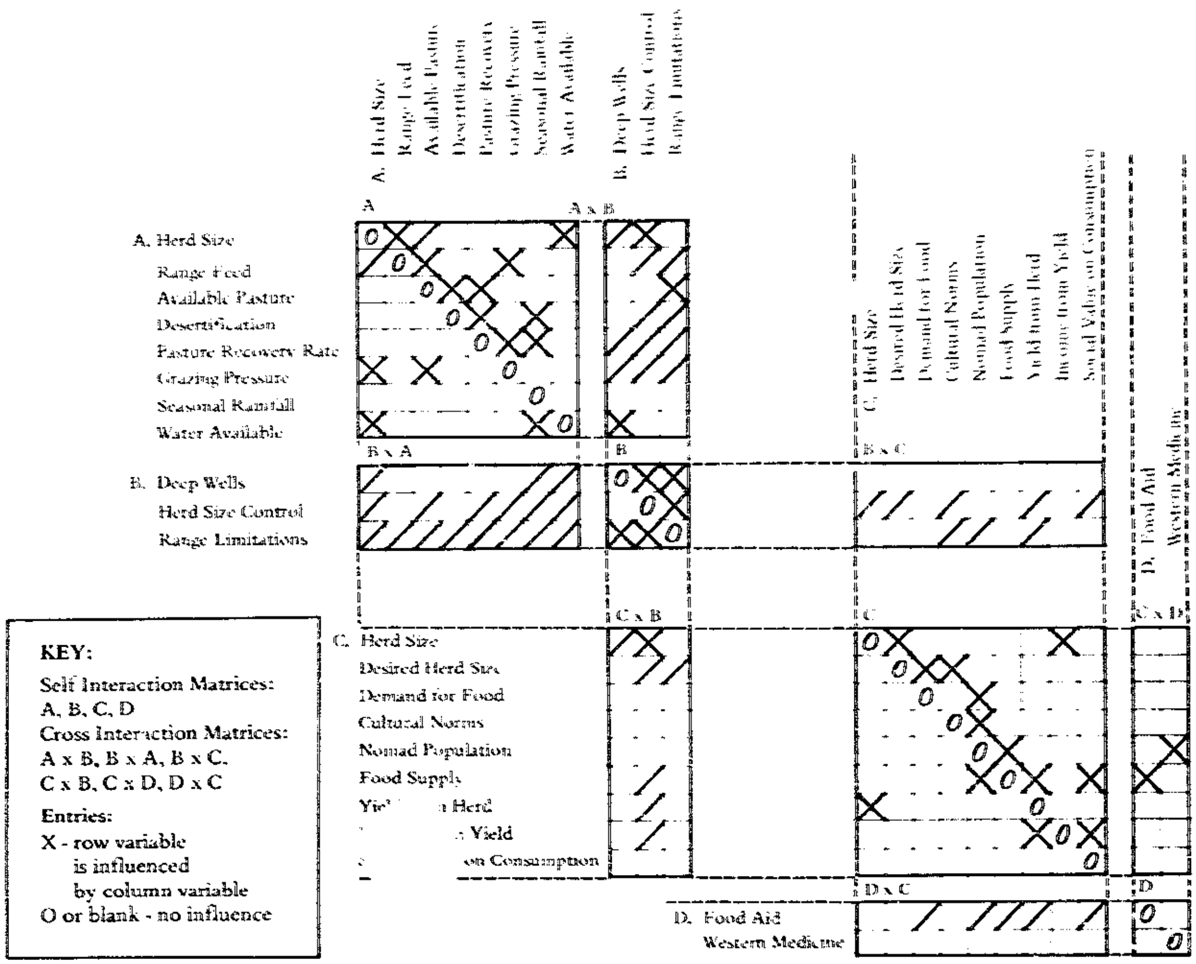
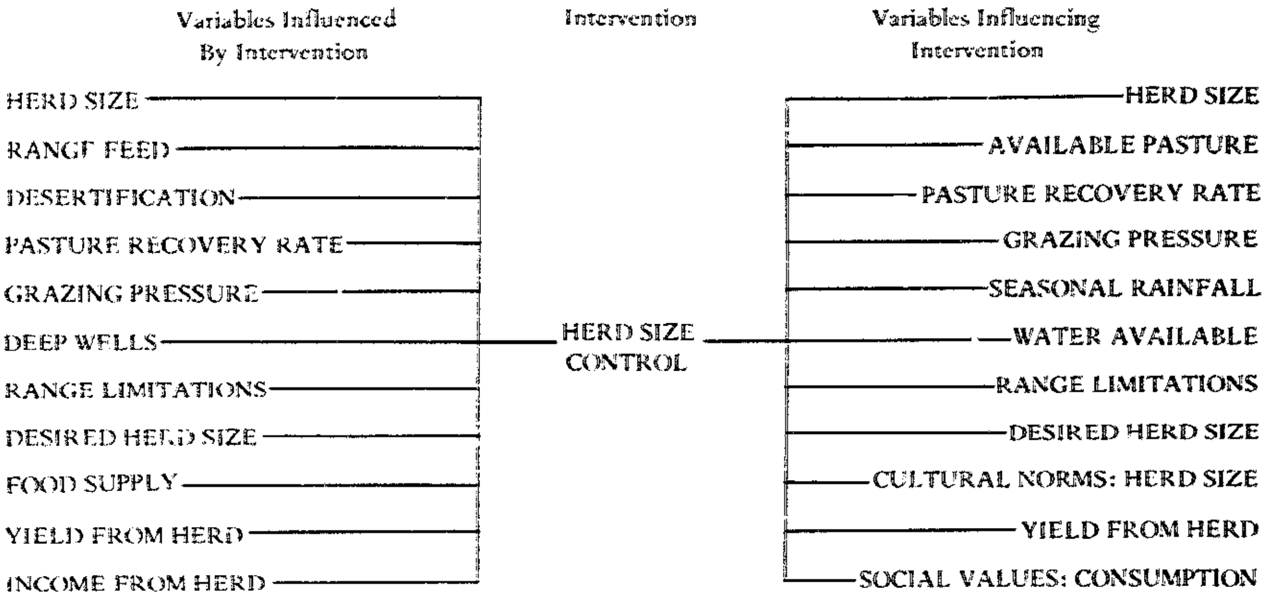


FIGURE 7
Tree Diagram Clarifying the Influence
Relationships in the Interaction Matrix Diagram Example



The problems of the nomad pastoralists in the Sahel have been addressed using Interpretive Structural Models in two recent papers (Geiger and Fitz, 1976, and Hornbach, et al., 1976). The papers present oval and tree diagrams which were derived with the assistance of special computer programs designed to transfer the interaction matrix representations.

THEORY

The matrix representation of relationships takes many forms, and the relevant theory depends on the particular application. Beckett (1971) traces the representation of systems from directed graphs (oval diagrams) to matrix models (interaction matrices) to Markov transition models. The latter builds on probability theory with the matrix entries representing the probability of a transition from one system state to another.

Interaction matrix diagramming owes a great deal to the efforts of Warfield and others at the Battelle Memorial Institute (Hill and Warfield, 1972). Their "Unified Program Planning" uses the self-interaction and cross-interaction matrix approach to structure the following sets of planning elements:

Constraints
Needs
Objectives (and measures)
Alterables
Agencies (and agents)
Activities (and measures)
Societal sectors

These techniques and others are described in *Portraits of Complexity* (1975).

Interpretive Structural Modeling is the label for a range of computer-assisted diagramming techniques which grew out of the work at Battelle (Warfield, April, September, 1973; 1974). It relies on computer assistance to manipulate the matrices of relationships into a model and provides a powerful technique for automatically analyzing large numbers of complex interactions. The basis for computer assistance is found in the properties of directed graphs and matrix partitioning. These techniques may be performed manually, but are tedious for large matrices.

Gerardin (1973) describes an application of the technique to planning, and at a recent conference (IEEE Conference, 1976) several authors applied the technique to development problems.

The interaction matrix diagramming technique extracts the most useful elements of Interpretive Structural Modeling and the more heuristically oriented Unified Program Planning.

BIBLIOGRAPHY

Baldwin, Maynard M., ed. *Portraits of Complexity: Applications of Systems Methodologies to Societal Problems.* A Battelle Monograph, No. 9. Columbus, Ohio: Battelle Memorial Institute, April 1973.

Beckett, John A. *Management Dynamics: The New Synthesis.* New York: Mcgraw-Hill, 1971.

Environmental Assessment Guidelines Manual. Washington, D.C.: USAID, September 1974.

Geiger, Donald, and Fitz, Raymond. "Structural Modeling and Normative Planning for Eco-systems." *Proceedings of 1976 IEEE Conference on Cybernetics and Society.* Washington, D.C.: November 1976.

Gerardin, Lucien A. "Topological Structural Systems Analysis." *Systems Approaches to Developing Countries, Proceedings of the Symposium Sponsored by IFAC and IFORS.* Algiers, Algeria, May 28-31, 1973.

Hill, Douglas, J., and Warfield, John N. "Unified Program Planning." *IEEE Transactions on Systems, Man and Cybernetics.* Vol. SMC-2, No. 5, November 1972.

Hornbach, Daniel; Calfee, Judy; and Zamierowski, Edward. "Anticipating the Consequences of Development Projects: An Example of a Water Utilization Project." *Proceedings of 1976 IEEE Conference on Cybernetics and Society.* Washington, D.C.: November 1976.

Proceedings of 1976 IEEE Conference on Cybernetics and Society. Washington, D.C.: 1976.

Warfield, John N. *An Assault on Complexity.* A Battelle Monograph, No. 3. Columbus, Ohio: Battelle Memorial Institute, April 1973.

Warfield, John N. "Binary Matrices in System Modeling." *IEEE Transactions on Systems, Man, and Cybernetics.* Vol. SMC-3, No. 5, September 1973, pp. 441-49.

Warfield, John N. *Structuring Complex Systems.* A Battelle Monograph, No. 4. Columbus, Ohio: Battelle Memorial Institute, 1974.

V
Analyzing Complex Processes

Flowcharts
Decision Tables
Computer Simulation Models
Gaming

Project planning demands analysis of the complex processes of development. Static descriptions are useful for characterizing complex relationships, but dynamic analysis takes the description into the time dimension. A powerful technique for dynamic analysis utilizes the versatility of electronic computers (Computer Simulation Models) to examine the processes which bring about changes in systems. The computer is not an absolute requirement, as other means of simulation can be used to explore complex processes. Two analysis techniques (Flowcharts and Decision Tables) focus directly on the sequences of decision and action which characterize systems performance.

Flowcharts

PREREQUISITE TOOLS

None.

USAGE

PURPOSE

A flowchart represents complex processes as a connected sequence of decisions and alternative actions.

USES

A flowchart is used to:

1) Present the analysis of a complex decision situation or procedure which can be broken down into identifiable processes.

2) Depict a complex sequential process such as the steps in planning and implementing a project.

3) Indicate how a repetitive activity is to be carried out, e.g., the routine tasks in controlling project disbursements.

4) Design, analyze, and debug computer programs.

KEY DEFINITIONS

1) A *process symbol* represents an action which takes place over time (see figure 1).

2) A *decision symbol* represents a step in a process where there is a choice among two or more alternative actions (see figure 1).

3) A *state symbol* represents a tangible product, requirement, or specific condition associated with a process sequence (see figure 1).

4) A *directed line* links two symbols together with an arrowhead indicating the sequence (see figure 1).

SHORT DESCRIPTION

A flowchart consists of process, state, and decision symbols which are combined to show the sequence or flow of a complex process. The process may be the steps necessary to achieve a task, a series of decisions where choices are dependent on earlier choices, or the routing of information and materials in a system (see System Definition Matrix, SDM, page 67).

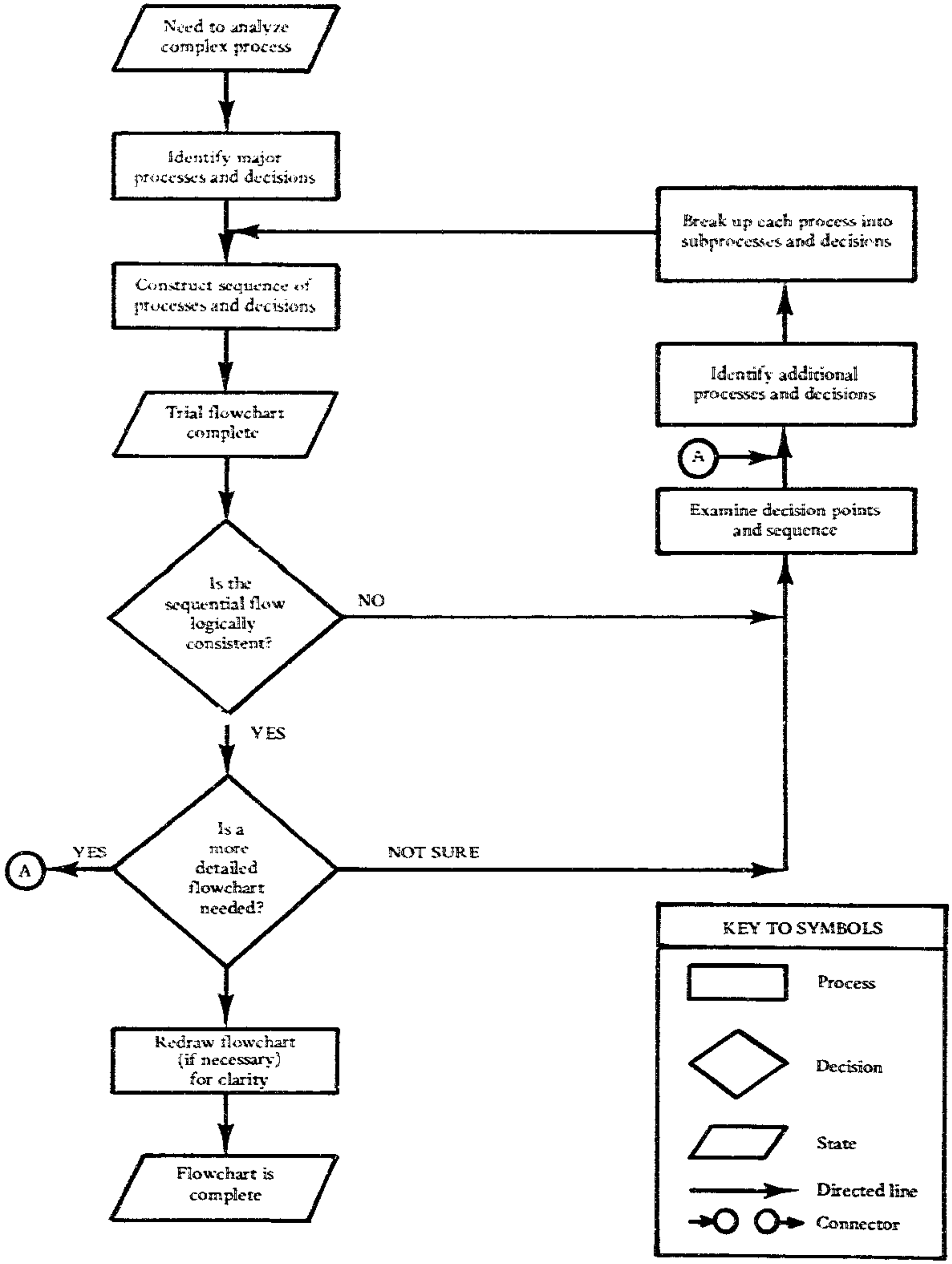
The symbols are linked by directed lines to indicate the order of occurrence (see figure 1). If a decision has an alternative which requires the repetition of a process or decision, then the flowchart depicts the feedback loop.

ADVANTAGES

1) Flowcharts are relatively simple to use and have wide applicability.

2) The graphic description of a complex process makes it easier to communicate with others.

FIGURE 1
A Flowchart for the Task of Constructing a Flowchart



3) Alternative courses of action are related to successive steps by their location on the flowchart.

4) The position of an activity in the overall task is clearer than in prose descriptions.

5) Logical inconsistencies in decision sequences can be identified, e.g., a portion of a computer program that cannot be executed because no action sequence leads to it.

LIMITATIONS

1) Constructing a flowchart may be somewhat more difficult than a simple prose account or the construction of a decision table (DTB, page 113). It is easier to overlook processes and decisions.

2) Modifying to include new processes or decision choices may require redrawing the flowchart.

3) A flowchart is less effective as an analysis tool where a large number of options are associated with a decision.

REQUIRED RESOURCES

LEVEL OF EFFORT

Effort is expended in identifying possible decisions, determining the processes required to carry out the activity, and constructing a flowchart which links these decisions and processes.

SKILL LEVEL

Flowcharting requires the ability to anticipate the scope of the project and to break down the project into a sequence of activities. Flowcharting becomes easier with practice.

TIME REQUIRED

The time required depends on the number of activities and the complexity of the sequence. A flowchart describing a sequence of 100 steps may take approximately a day to construct and refine for clarity.

DESCRIPTION OF TOOL

REQUIRED INPUTS

Flowcharts are combinations of symbols:

The *process symbol* describes an action or step in the overall process. The level of detail necessary to describe a process depends on how the chart is to be used (greater detail could lead to cluttering the diagram). Consequently, flowcharting requires identification of distinct actions within the complex process or system.

The *decision symbol* is another building block for flowcharts. It always contains a question like:

1) Did a particular event occur?
2) Has a specified criterion been met?
3) Is a prior process complete?

Question 1 is answered by a simple binary choice - yes or no. These answers are associated with the arrows emitting from the decision symbol and leading to subsequent symbols in the chart.

Question 2 may be answered by yes or no, or the specific criteria may be shown as branches emitting from the flowchart decision symbol (see figure 2).

Question 3 is a specific case of question 1 (the event is the completion of the prior step) and illustrates a common occurrence in the flowchart. The branch labeled NO will likely loop back to the prior symbol if the process cannot continue until that step is completed (see figure 2).

The *state symbol* is an optional, though useful, component of flowcharts. It is used to identify the resources needed (inputs) or the result of a process (outputs). The state symbol can also indicate the state of the activity at a specified point in time, e.g., the conditions necessary before disbursement of loan payments to a host country.

A pair of connector symbols, often used in flowcharts to promote clarity, permits breaking the line linking two symbols to avoid crossing lines or to connect portions of a flowchart on separate pages (see figure 1). The same letter or number should be used in each circle.

Any number of other symbols can be used in flowcharting as long as a suitable explanation of the significance of the shape is given. Otherwise, the different symbols may fail to communicate a complex decision process.

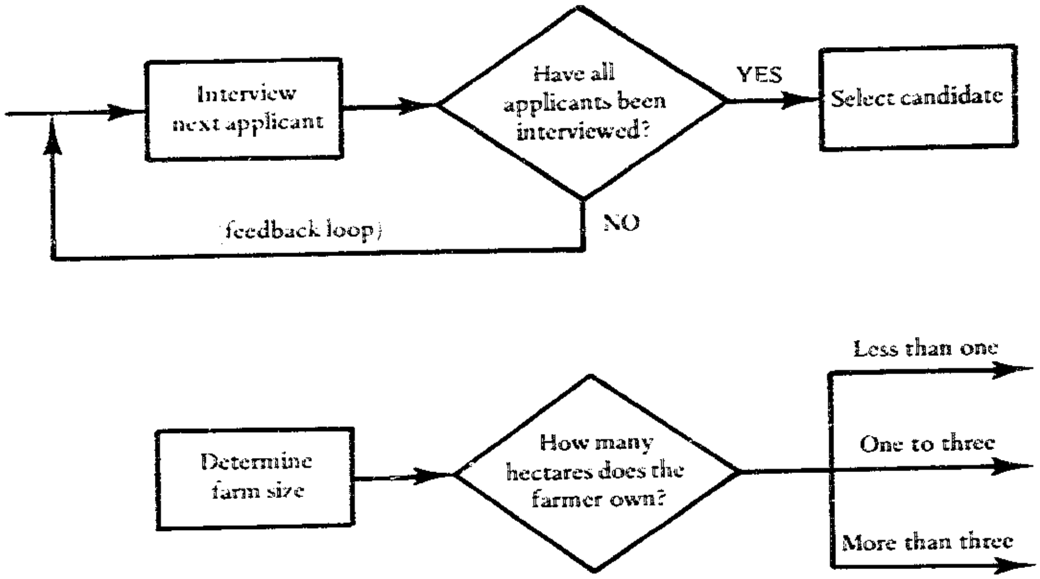
The Delta chart (described by Warfield and Hill, 1971) is a flowchart designed specifically as a planning and control tool. It provides more symbols (e.g., logic elements) and incorporates a larger amount of data (e.g., the person or organization responsible for a process and the time involved in carrying out a process).

TOOL OUTPUT

The flowchart is a planning tool that indicates how an activity can be carried out in the future. The planner may find the flowchart useful as a control tool if he identifies who is responsible for what process and if he specifies the timing of the processes.

The flowchart provides a description not only for design and analysis purposes, but for repeated use in the operational phases of a project. The operator follows the

FIGURE 2
Examples of Decision Points for Flowcharting



sequence of processes described and branches at each decision point according to the current conditions affecting the decision. In this regard, the decision table may be more useful than a flowchart (see DTB, page 113).

IMPORTANT ASSUMPTIONS

Flowcharts belong to a set of techniques which, even though allowing for various contingencies, assume that a fundamental determinacy underlies the diagrammed process. There is an underlying logic or basic rationality which must hold for the process. Otherwise the combination of decisions, actions, and states is meaningless.

This feature of flowcharts suggests their use in testing the logic and coherence of a prose description of a complex process. If the charted sequence does not "flow" logically, then perhaps the process being described is incoherent or inconsistent.

METHOD OF USE

GENERAL PROCEDURE

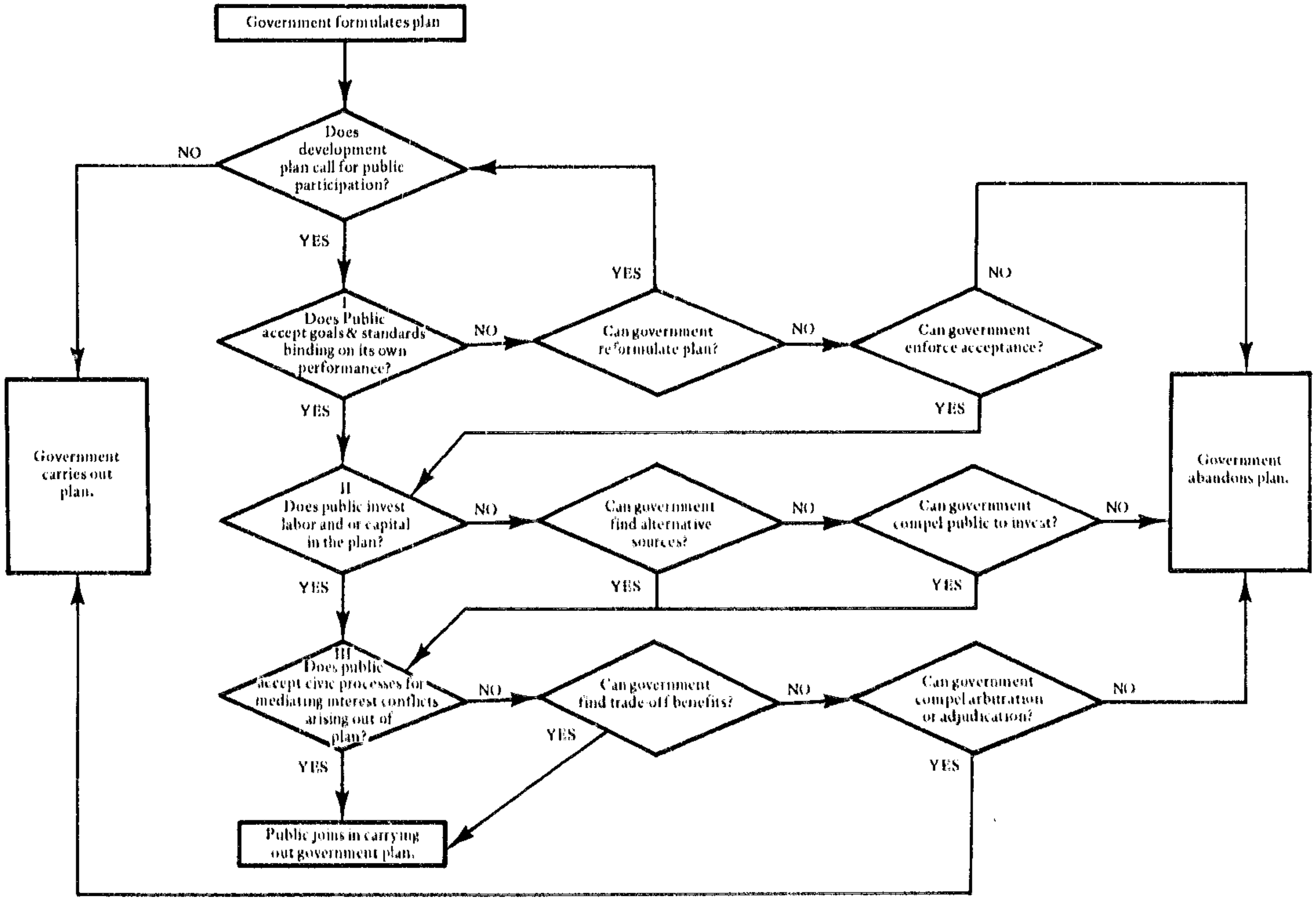
Constructing a flowchart is primarily a heuristic task: only general guidelines can be given. Be careful not to get bogged down in details; rather, start with a high level of abstraction to capture the basic processes and major decision points. The first chart should give a broad representation of the overall process. More detail may be added in successive versions.

The following steps are useful guidelines for describing a complex process which follows a more or less logical sequence from start to finish.

1. Identify major processes and decisions.
2. Single out those processes (and decisions) which represent the basic activity accomplished.
3. Order these in a sequence of successive symbols and sketch the basic flow by showing only the connections which represent the most likely choice at each decision point.
4. Identify the conditions which must be met before each decision can be made and connect them by arrows entering the flow before the decision point.
5. Identify the alternatives at each decision point and show these as labeled branches emitting from the decision symbol.
6. Rather than show a symbol for a process which must be repeated, loop back to the symbol representing the first occurrence of that process.
7. Examine the chart for consistency.
8. If further detail is desired, break the processes into subprocesses and insert additional decision points as required.

If the complex process is primarily a series of decisions, then the ordering in step 3 should reflect the logic of the questions asked, e.g., from general to specific, or in a selection process, those decisions which lead to an early acceptance or rejection, e.g., minimum qualifications which must be met for job applicants.

FIGURE 3
Behavioral Model of Development Administration



NOTE: Reprinted from *Technology and Civic Life* by John D. Montgomery by permission of the MIT Press, Cambridge, Massachusetts.

EXAMPLE

The degree to which the public reacts to a plan which calls for public participation significantly affects the planning process and the ultimate course of action. Montgomery (1974) poses a series of questions which lead to three actions: 1) the government carries out the plan without public participation except as compelled by arbitration or adjudication; 2) the public participates in carrying out the plan; or 3) the plan is abandoned. Figure 3 presents a flowchart of the questions for determining which alternative is likely to occur.

Other examples may be found in the descriptions of Interaction Matrix Diagrams (IMD, page 92) and Scenarios (SCN, page 164).

THEORY

Flowcharts belong to a set of approaches for pictorially describing complex processes. Nadler (1970) describes many of these variations, all of which depend on the analyst's ability to abstract complex decisions and operations. This is a particularly useful skill for computer programmers where the logical flow of calculations and data manipulation may be traced.

The same idea may be used to describe any system or deterministic task. Signal flow graphs and networks are flowcharts with different symbols for representing the elements (Whitehouse, 1973). Basic laws have been developed for simplifying these representations, though their application to flowcharts is more difficult.

Decision tables have a one-to-one correspondence to flowcharts (see DTB, page 113). This format for analyzing a complex process lends itself to certain principles of simplification (see Lewis, 1970).

BIBLIOGRAPHY

Lewis, Brian N. *Decision Logic Tables for Algorithms and Logical Trees.* London: Her Majesty's Stationery Office, 1970.

Montgomery, John D. *Technology and Civic Life: Making and Implementing Development Decisions.* Cambridge, Mass.: MIT Press, 1974.

Nadler, Gerald. *Work Design: A Systems Concept.* Homewood, Ill.: Richard D. Irwin, 1970, pp. 258-62.

Warfield, John N., and Hill, J. D. "The Delta Chart: A Method for R & D Project Portrayal." *IEEE Transactions on Engineering Management* EM-18, 4 (November 1971): 132-38.

Whitehouse, Gary. *Systems Analysis and Design Using Network Techniques.* Englewood Cliffs, N.J.: Prentice-Hall, 1973.

Decision Tables

PREREQUISITE TOOLS

None.

USAGE

PURPOSE

A decision table documents a decision-making process by describing *actions* to be followed under different *conditions* in a given environment.

USES

Decision tables are used to:

1) Analyze complex decision situations.

2) Provide a documented procedure for handling decisions which may re-occur under different conditions.

3) Record and communicate procedural rules and regulations within organizations.

4) Provide the basis for writing computer programs for use in tools such as Computer Simulation Models (CSM, page 120).

KEY DEFINITIONS

1) The *condition stub* is that portion of a decision table which lists the factors to be considered when making decisions in a given situation. Each factor is written in the form of a question, e.g., "Are loan funds available?"

2) The *condition entries* are the conditions of each factor (or question) listed in the condition stub, e.g., "YES—loan funds are available."

3) The *action stub* is that portion of a decision table which lists the actions or decisions to be taken if a particular combination of circumstances occurs, e.g., "submit fund transfer request."

4) The *decision rules* are the action entries of a decision table which link a particular combination of condition entries to specified actions.

SHORT DESCRIPTION

A decision table is a tabular representation of a complex decision process where a number of factors affect the choice of action(s). The table has four parts: the *condition stub*, the *condition entries* or contingencies, the *action stub*, and the action entries or *decision rules* (see figure 1). The table is used by first determining the conditions which apply (e.g., loan funds are available, but the government has not deposited its contribution), and then by matching the condition entries to this contingency to determine the decision rule column (e.g., column 2). The actions to be taken (or the decision choices) are indicated by X's in the column. The "X" may be interpreted thusly: If these conditions occur, then these actions are specified.

Decision tables may be interconnected to present complex sequential decision processes.

FIGURE 1

Decision Table Used by Donor Agency for Depositing Loan Funds into Special Program Account

	CONDITIONS	DECISION RULES 1	2	3	4	
CONDITION STUB	Are loan funds available?	NO	YES	YES	YES	CONDITION ENTRIES
	Has government contribution been deposited?	–	NO	YES	YES	
	Has release of funds been authorized by government?	–	–	NO	YES	
ACTION STUB	ACTIONS					ACTION ENTRIES
	Submit fund transfer request.	X				
	Resolve constraints with Ministry.		X	X		
	Deposit funds in SSPA.*			X	X	
	Authorize release of funds from SSPA.				X	

*Special Segregated Program Account for disbursement of funds to programs.

ADVANTAGES

1) Decision tables are a concise method of describing situations.

2) Standard techniques are available to ascertain that there are no omissions or inconsistencies in the table.

3) Decision tables aid in understanding and communicating complex situations.

4) The decision table is easily adapted for computer programming.

5) A complex decision involving several factors (each of which may assume multiple values) typically requires a specification of a different action for each combination of factor values. This process is more easily represented on a decision table than by a prose description or a flowchart (see FLW, page 107).

LIMITATIONS

1) A flowchart has greater visual clarity for understanding the different courses of action in a complex procedure.

2) Decision tables are relatively little used and may deter the uninitiated until the mechanics are mastered.

REQUIRED RESOURCES

LEVEL OF EFFORT

Effort is required to identify the different conditions in a situation and the actions to be taken when specific conditions occur. Developing the table requires little additional effort.

SKILL LEVEL

The ability to logically break down a decision into relevant factors and decision rules for action is fundamental to constructing decision tables. Their use requires little skill once the format is understood.

TIME REQUIRED

The time required to develop a decision table depends on the complexity of the decision situation. Less than an hour is required to develop a decision table with 5-8 conditions, 8-10 actions, and 10-15 rules. Additional time is required if several interconnected tables are needed to describe the situation.

DESCRIPTION OF TOOL

SUPPLEMENTAL DEFINITIONS

1) A *limited entry* decision table permits only a limited set of condition and action entries in the decision rule columns, e.g., YES or NO (see figure 1).

2) A *mixed entry* decision table permits extended entries such as a range of values for a question, "What is the size of the land holding?" in the condition stub.

3) The *ELSE rule* is a column in the decision table which applies when no other decision rules may be added to cover the case or where no combination of conditions applies.

REQUIRED INPUTS

Construction of a decision table requires a breakdown of the factors relevant to the decision and the possible action choices. The analyst must consult with the decision maker on policy and conditions affecting the policy if the table is to be used as a guide for action.

TOOL OUTPUT

The decision table technique results in an analysis of the conditions and actions which compose a particular decision. The process may be valuable in itself to point out inconsistencies in procedure or areas where further specification of action is in order.

IMPORTANT ASSUMPTIONS

The decision table technique assumes that the decision process can be rationalized, and thus actions are prespecified. All relevant conditions must be identified a priori, i.e., all the actions which follow from a given set of conditions can be specified. The implication of a preprogrammed automatic response is somewhat counteracted by including an ELSE rule in the set of decision rules. This permits an escape clause if none of the relevant conditions hold, or if the analyst chooses not to specify every possible combination of circumstances. The action for the ELSE rule is almost always to call it to the attention of a supervisor or higher level decision-making authority.

METHOD OF USE

GENERAL PROCEDURE

Constructing a Limited Entry Table

1. **Fill in the condition stub of the table (upper left quadrant).**
   - 1.1 Determine the conditions which are relevant to the decision.
   - 1.2 Write each condition in the form of a yes/no question.
   - 1.3 List the conditions in the condition stub.

2. **Fill in the action stub of the table (lower left quadrant).**
   - 2.1 Determine the action options which correspond to each possible combination of conditions.
   - 2.2 List the actions in the action stub.

3. **Specify all possible contingencies (upper right quadrant).**
   - 3.1 Enter a YES or NO to the first condition (or simply Y or N) in the table at the first rule column (see figure 1).
   - 3.2 If the other conditions are relevant, enter a YES or NO for each remaining condition in that column; if not, enter a "-".
   - 3.3 Repeat this for the remaining columns until all possible combinations of conditions are marked. Each combination represents a contingency and occupies a single column in the table.
   - 3.4 Confirm that if there are n questions in the condition stub, then there are 2^n contingencies (unless some combinations are not feasible).

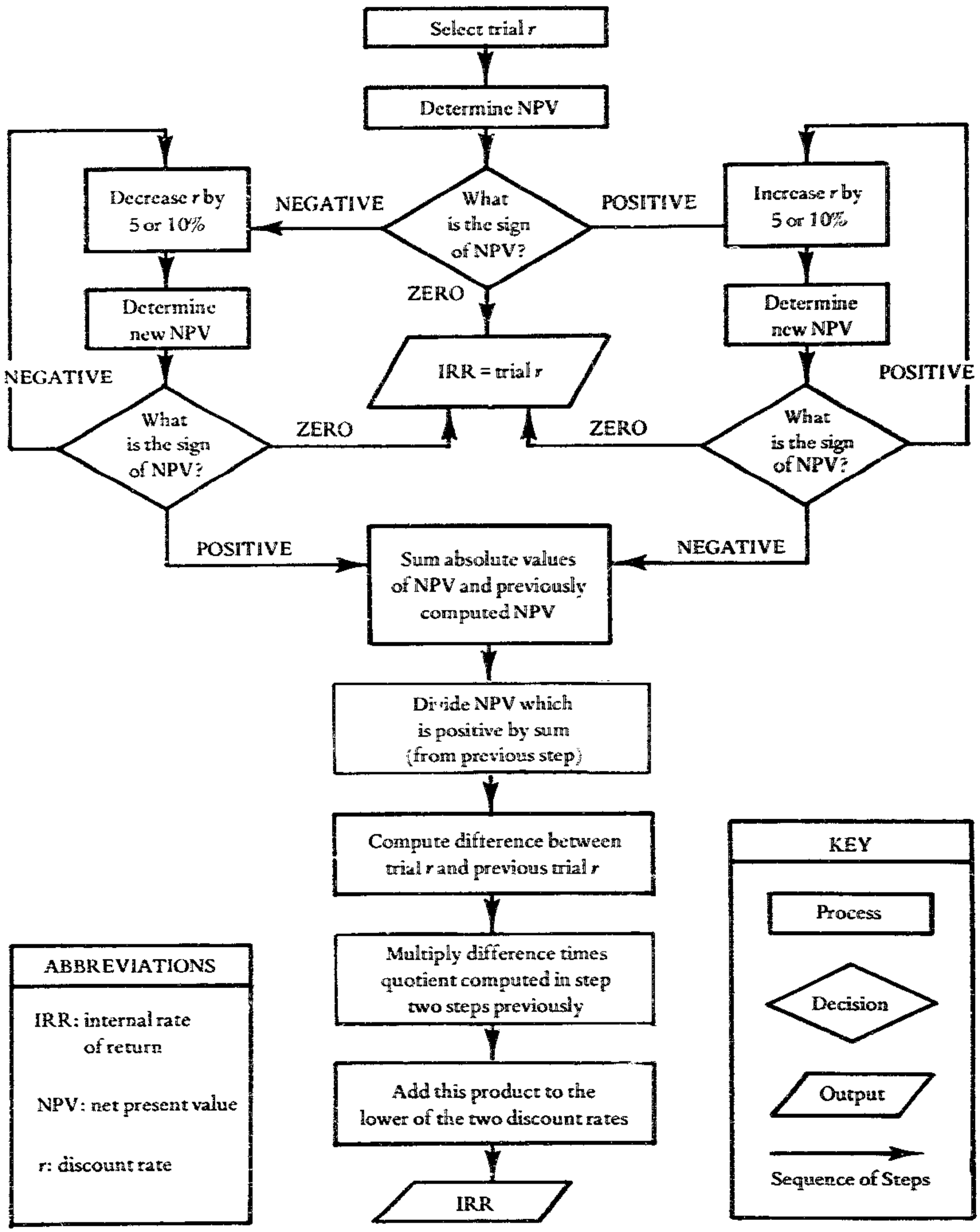
4. **Enter the decision rules (lower right quadrant).**
   - 4.1 Start with the first contingency (column 1) and indicate the appropriate action with an X at the intersection of the column with the corresponding action row.
   - 4.2 Repeat this process for each contingency until all columns have at least one entry in the bottom portion of the table.

5. **Simplify the table if possible.**
   - 5.1 Order the decision rules from left to right so that the rule which is indifferent to the most number of conditions is the first decision rule column.
   - 5.2 Order the condition questions so that the decision rules are applied first to the contingency where the least number of questions must be asked. Steps 5.1 and 5.2 should result in the condition entries occupying the upper right triangle with an increasing number of indifferent entries (–) in the lower left portion (see figure 1).
   - 5.3 Combine any two decision rule columns which differ only by the answer to one condition question and mark the entry as indifferent, since the choice of action will not be affected.

Constructing an Extended Entry or Mixed Entry Table

Extended entries permit more flexibility in the formulation of conditions and decision rules. Otherwise, the procedure is the same. For example, step 1.2 requires only that the question be posed in such a way that a finite set of conditions can be written in the contingencies portion of

FIGURE 2
Flowchart of Interpolation Procedure to Determine Internal Rate of Return



the table (e.g., farm size in hectares). Furthermore, the decision rule entries need not only refer to the action row, but may indicate:

1) A further specification of the action, such as the quantity of fertilizer to be distributed, or

2) Instructions to go to another step or to another decision table.

A column may be added which includes all contingencies not otherwise described. This ELSE rule is to be followed when none of the combinations of conditions apply.

A mixed entry table combines limited entry symbols (e.g., *Y*, *N*, *X*) with extended entries. These may include a decision rule to go to another decision table if a particular contingency occurs or the ELSE rule.

EXAMPLES

Limited Entry Decision Table

A capital projects development officer for a major donor agency wanted to ensure that funds released by his agency were matched by the required ratio of funds from the host government.* The government had failed to contribute their share of funds in the past. Often, when the required funds were budgeted, they were later diverted to other programs.

In order to exercise more control over the use of the donor's funds and the requirement for cost-sharing by the government, a Special Segregated Program Account (SSPA) was established. The donor agency mission would then deposit and release funds if the Ministry of Finance had fulfilled its obligations. A limited-entry decision table was prepared to guide the disbursement policy (see figure 1).

The decision table was arranged so that the capital development officer need not examine the other conditions unless the necessary initial conditions occurred, e.g., loan funds are available.

Mixed Entry Decision Table

Computing the internal rate of return (IRR) for a project is an iterative process: the discount rate, r, must be found which gives a net present value, *NPV*, equal to zero (see Internal Rate of Return, IRR, page 200). However, if one has computed both a positive (NPV_1) and negative (NPV_2) net present value using two different trial discount rates, r_1 and r_2, respectively, the IRR may be interpolated using the following formula:*

$$\text{IRR} = r_1 + (r_2 - r_1) \times \frac{NPV_1}{(NPV_1 - NPV_2)}$$

The steps necessary to calculate the IRR can be represented as a flowchart (see figure 2). Recouching this procedure in the decision table format requires the combination of a sequential procedure with an iterative process. This may be necessary in order to get both positive and negative *NPV*s (see figure 3).

The ELSE rule was employed where the *NPV* determined from a trial r is zero, in which case the IRR equals r.

The decision table (figure 3) is a mixed entry table because the iterative actions include extended entries.

An illustration of interpolating the IRR for a project cash flow is given in the technique description (IRR, page 200).

THEORY

Decision tables belong to a class of techniques which are categorized as logical trees or algorithms (Lewis, 1970). The underlying idea is the linking of contingencies (combinations of conditions) with the appropriate action according to a set of prespecified decision rules. The decision table has a one-to-one correspondence with a flowchart (see FLW, page 107). Each rule in the decision table corresponds to a path in the chart. Decision tables may be simplified by applying certain rules of logic so that, if the same actions apply, it is usually unnecessary to show every sequence of alternatives or every combination of conditions. This is treated in more detail in Fergus (1974), Hartman (1968), and McDaniel (1970).

Extended entries add more flexibility to the decision table, but they require more care in construction. Nadler (1970) and Pollack, et al. (1971) give more information on the technique.

BIBLIOGRAPHY

Fergus, R. M. "Decision Tables: What, Why and How." In *Systems Analysis and Techniques*, edited by J. D. Gouger and R. W. Knapp. New York: John Wiley and Sons, 1974, pp. 162-80.

*This example is from a tutorial project by Ted Foley, "Systems Approaches to Integrated Rural Development Program," Development Studies Program, USAID, Washington, D.C., 1976.

*This equation is adapted from J. Price Gittinger, *Economic Analysis of Agricultural Projects* (Baltimore: The John Hopkins University Press, 1972), page 80. Note that the denominator on the right is the sum of the absolute values of the positive and negative *NPV*s. Gittinger suggests that the difference between r_1 and r_2 be 5% or less.

FIGURE 3
Mixed Entry Decision Table for Determining Internal Rate of Return by Interpolation

		RULES				
						ELSE
	1. Select trial *r*					
	2. Determine NPV					
CONDITION STUB	3. What is sign of NPV?	Positive	Negative			
	4. Determine new NPV					
CONDITION STUB	5. What is sign of NPV?	Positive		Negative		
	6. Determine new NPV					
CONDITION STUB	7. What is sign of NPV?		Negative		Positive	
ACTION STUB	IRR += trial *r*					X
ACTION STUB	Iterations until NPV changes sign (or is zero)	Increase *r* by 5 to 10% Go to step 4	Decrease *r* by 5 to 10% Go to step 6			
ACTION STUB	8. Sum the absolute values of NPV and previously computed NPV			X	X	
	9. Divide NPV which is positive by sum computed in step 8					
	10. Compute difference between this trial *r* and previous trial *r*					
	11. Compute product of difference and quotient computed in step 9					
	12. Add this product to lower of the last two trial discount rates					
	13. Result is the IRR					

NOTE: *r* = discount rate; IRR = internal rate of return; NPV = net present value.

Hartman, W.; Matthes, H.: and Proeme, A. *Information Systems Handbook.* Appledoorn, Netherlands: Philips Data Systems, 1968.

Lewis, Brian N. *Decision Logic Tables for Algorithms and Logical Trees.* London: Her Majesty's Stationery Office, 1970.

McDaniel, H. *Applications of Decision Tables.* Brandon/Systems Press, 1970.

Nadler, Gerald. *Work Design: A Systems Concept.* Homewood, Ill.: Richard D. Irwin, 1970. pp. 258-62.

Pollack, S. L.; Hicks, H. T.; and Harnnon, W. J. *Decision Tables: Theory and Practice.* New York: Wiley-Interscience, John Wiley and Sons, 1971.

Computer Simulation Models

PREREQUISITE TOOLS

None.

USAGE

PURPOSE

Computer simulation models simulate dynamic system processes in order to analyze complex interactions.

USES

Computer simulation is used to:

1) Forecast future systems behavior.

2) Forecast the effects different decisions have on system variables.

3) Aid in understanding system processes.

4) Be used in tools like Gaming (GAM, page 124).

5) Compare alternative system behavior or determine optimum system design parameters.

KEY DEFINITIONS

1) A *system* is a collection of components which interact to achieve a common function.

2) A *variable* is a factor word to describe a system which may change value as a function of time.

3) A *parameter* is a quantity with only one value over the entire range of the system behavior being simulated. The distinction between a parameter and a variable is sometimes only a matter of degree of change. In the model, the parameter is assumed not to change during the course of a particular simulation, e.g., "the price of gold" may be a parameter in an economic system.

4) *Verification* is testing a computer simulation program to see that the program functions as intended. It is a process of eliminating logical errors in the program.

5) *Validation* is testing whether a computer simulation program simulates the observed system behavior. It is a process of simulating the past and checking the simulated data against actual data.

SHORT DESCRIPTION

A computer simulation involves:

1) Developing a model of the simulated system.

2) Programming the model in a computer.

3) *Verifying* the internal consistency of the model.

4) *Validating* the model by comparing it with observed system behavior. Past and present data are needed in all stages of computer simulation.

Computer simulations are exploited by changing parameters to correspond with expected changes in the system. Present and future system behavior is then inferred.

ADVANTAGES

1) Computer simulation is useful for problems which cannot be studied analytically. Typically, problems necessitating computer simulation involve detailed models of complex systems with non-linear and probabilistic behavior.

2) Systems which require expensive or impractical experimentation may be simulated in a computer. For example, the performance of a dam or reservoir can be studied using a computer simulation rather than by building different dams.

3) A wide range of alternatives can be studied, since changing computer models is relatively fast and easy.

4) Complex assumptions can be easily incorporated into a computer model. For example, in a macro-economic model, a wide range of assumptions, including those about price stability, exchange rate, limitations of natural resources, and climatic catastrophes, can be incorporated in a simulation model.

5) Computer simulation may provide insight into the causal structure of the system by revealing dynamic behavior.

LIMITATIONS

1) Data may not be available to construct and/or test a computer simulation model.

2) Computer simulation models may become so complex that assumptions are hidden and the ability to infer underlying system processes is lost.

3) Developing large computer simulation models is time-consuming. Verifying and validating entire models are often difficult.

4) A computer simulation provides only a specific instance of system behavior. Generalized inferences do not always follow.

5) Conclusions derived from a computer simulation are only as reliable as the model upon which the simulation is based. The user of the results may forget that the model is an abstraction based on the developer's assumptions. Too much weight may be placed on the results and conclusions because they are quantified.

REQUIRED RESOURCES

LEVEL OF EFFORT

Gathering data, developing a model, and verifying and validating the computer simulations are necessary. Using specialized computer simulation languages will often reduce the amount of effort involved.

Techniques are available that aid in developing models for computer simulation: Oval Diagramming (OVD, page 81), Interaction Matrix Diagramming (IMD, page 92), and Decision Tables (DTB, page 113).

Several computer languages also simplify the process, e.g., DYNAMO, GPSS, and GASP (see Gordon, 1969).

SKILL LEVEL

Knowing about the system being simulated is required. An analyst must have the computer usage skills and the basic statistical knowledge needed to develop and use computer simulation models.

TIME REQUIRED

Time required depends on the number of variables included in the model and the availability of data. Typically, developing the model may take a week; programming the model may need another week; verifying and validating the model take a third week. However, the complexity of the system model (number of variables and relationships) will greatly influence the time it takes to develop, verify, and validate the model. Testing alternatives by simulation may require several runs or it may continue for the duration of the project. These estimates assume that the data required are easily available. Additional time may be needed if Surveys (SVY, page 36), Questionnaires (QTN, page 19), or other tools have to be used to obtain data.

SPECIAL REQUIREMENTS

Access to a digital computer is necessary. Many specialized simulation languages may be used successfully on a remote computer terminal using purchased computer access time.

DESCRIPTION OF TOOL

SUPPLEMENTAL DEFINITIONS

1) *Tuning* is the process of making changes in the parameters and initial values for variables in order to minimize the errors between expected and actual simulation output or the errors between observed or simulated data.

2) A *continuous model* treats variables that change continuously over time, e.g., population.

3) A *discrete stochastic model* describes the changes in variables at definite points in time, e.g., money supply increases on the day the Federal Bank releases notes. Often, the time interval between these points in time varies randomly.

REQUIRED INPUTS

The purpose for simulation must be stated before a simulation can be developed. Data necessary for modeling the system and for validating results are required, though the data need not be gathered until variables and parameters are defined. If a particular programming language is preferred, a compatible computer must be available.

TOOL OUTPUT

The results from computer simulation models include:

1) A computer simulation model of the system under question.

2) Forecasts of system behavior under different assumptions (e.g., alternative parameter values).

3) A better understanding of the system and its behavior.

IMPORTANT ASSUMPTIONS

All the relevant variables and relationships can be quantified and all necessary data are available. It is assumed that all variables and relationships can be identified and defined explicitly.

METHOD OF USE

GENERAL PROCEDURE

Computer simulation cannot be described fully without reference to a specific type of model or a particular application. The following outlines only the steps basic to all computer simulations.

1. **Define the problem.**
   1.1 Recognize the system problem.
   1.2 Identify the system boundaries.
   1.3 Observe current and past system behavior.
   1.4 Formulate problem objectives.

2. **Develop the descriptive model.**
   2.1 Identify the important variables and the cause-effect relationships in the system.
   2.2 Identify the parameters of the system.
   2.3 Select the type of model to be developed.
   2.4 Develop the model to represent system behavior.

Two types of models will be discussed:

1) The *continuous model* where the change in the variables is expected to occur continuously (see Forrester, 1969). Computer languages like DYNAMO can be used here.

2) The *discrete stochastic model* where the change in the variables is expected to occur at specific points in time. These models are very popular in simulation. Many languages, including GASP and GPSS, are available for this model.

The model of system behavior may be traced through Flowcharts (FLW, page 107), Oval Diagramming (OVD, page 81), Decision Tables (DTB, page 113), or Interaction Matrix Diagrams (IMD, page 92).

3. **Computerize the model.**
   3.1 Select a programming language.
   3.2 Program the model.
   3.3 *Verify* the model.

4. **Validate the model using observed system data.**
   4.1 Tune the simulation model to correspond with past system behavior.
   4.2 Design experiments to test parameter values.
   4.3 Analyze the results of the experimental simulation.
   4.4 Statistically compare results with observed data.

5. **Simulate and infer.**
   5.1 Express policies or decisions as changes in parameter values or in some structural relationships.
   5.2 After making these changes, simulate the system model behavior and forecast the effects of these changes.

EXAMPLE

Continuous system models have been used by Forrester to model urban dynamics (1969). The Club of Rome has developed a model of the world predicting major changes in population, economy, etc. (Meadows, 1972).

Discrete event simulation has been used in a large and complex model of Nigerian agriculture (Abkin and Manetsch, 1973). Some 22 alternate policies and strategies were tested using this model.

THEORY

There are many types of simulation models that can be used. However, the types discussed above are the most popular and most widely used. Analogue computer simulation, where variables are represented analogously by currents and voltages in an electronic system constructed to resemble the observed system, can also be used. Also used are more complicated continuous models that include variables which are probabilistic in nature. Forrester (1968) discusses such models.

The use (and misuse) of large computer simulation models for urban problem solving is treated extensively by Brewer (1973). Standard textbooks on simulation methodology include Gordon (1969) and Emshoff and Sisson (1970).

BIBLIOGRAPHY

Abkin, M. H., and Manetsch, T. J. "A Generalized System Simulation Approach to Agricultural Development Planning and Policy Making." *Systems Approaches to Developing Countries.* Proceedings of the IFAL and IFORS Symposium, Algiers, Algeria, May 1973.

Brewer, G. D. *Politicians, Bureaucrats and the Consultant: A Critique of Urban Problem Solving.* New York: Basic Books, 1973.

Emshoff, J. R., and Sisson, R. L. *Design and Use of Computer Simulation Models.* New York: Macmillan, 1970.

Forrester, Jay W. *System Dynamics.* Cambridge, Mass.: The M.I.T. Press, 1968.

Forrester, Jay W. *Urban Dynamics.* Cambridge, Mass.: The M.I.T. Press, 1969.

Gordon, Geoffrey. *System Simulation.* Englewood Cliffs, N.J.: Prentice-Hall, 1969.

Meadows, D. H., et al. *The Limits of Growth.* New York: Universe Books, 1972.

Gaming

PREREQUISITE TOOLS

None.

USAGE

PURPOSE

Gaming provides decision makers with experience in a simulated *problem environment* in order to analyze complex processes.

USES

Gaming is used to:

1) Generate possible alternative actions in a problem situation (operational gaming).

2) Forecast effects of alternative actions.

3) Train present and potential decision makers (management gaming).

4) Provide experience in using different tools that assist in decision making, such as Contingency Analysis (CGA, page 147), Scenarios (SCN, page 164), and Computer Simulation Models (CSM, page 120).

KEY DEFINITIONS

1) The *problem environment* is the set of variables and relationships which are germaine to the decision process under study.

2) *Governing rules* describe the relationships between decisions made by the participants and the resulting changes in the simulated environment. For example, in an economic game a governing rule may dictate that a decision to expand money supply leads to inflation.

3) *Scoring* in games is used as feedback to the participants to reflect the effectiveness of their decisions. Scores are usually related to the objectives of the game. For example, "overall growth rate" may be used as a score in an economic game.

SHORT DESCRIPTION

Gaming consists of a controlled situation where people or teams compete either against each other and/or against a simulated problem environment to attain predetermined objectives. Games include a problem environment, several *governing rules*, and *scoring*, all of which are designed to represent a real situation. In games where two or more teams are participating, one team's decisions influence other teams' reactions and decisions. A single team may compete against a problem environment in which one or more variables are beyond the team's direct control. There are programmed relationships between the players' decisions and the resulting changes in the environment. However, the nature of the relationships is usually not known to the participating teams, and thus participants become involved in analyzing complex processes.

ADVANTAGES

1) Decision makers gain experience without paying the real-life penalties for wrong decisions.

2) A game can be designed to be very flexible and can provide a wide range of problem situations.

3) Because the time element is limited, the player can make as many decisions in a few hours as he would make in a few years in real life.

4) Gaming helps everyone involved, including the analyst who designed the game, to understand a problem.

5) Games have been developed for typical problem environments and can be applied directly. The American Management Association provides a list of such games.

LIMITATIONS

1) Games representing large and complex real situations may be difficult to construct.

2) A game requiring four to fifteen hours requires considerable concentration from the participants.

3) The compressed time element in a game may mislead the decision maker as to the real nature of the dynamic change in the problem environment.

4) Governing rules in a game reflect the designer's knowledge and experience in the problem situation and thus are a limited representation of reality. Often novel approaches, which may be appropriate in real life, work poorly in games, stifling the decision maker's creativity.

REQUIRED RESOURCES

LEVEL OF EFFORT

A considerable amount of effort is required to develop a game for a problem situation. A moderate amount of effort is required from the participants. Some elaborate game situations may use analysts and staff assistants as participants to assist the decision maker.

SKILL LEVEL

Developing a game requires expertise, primarily in the problem environment being simulated. Complex games require a team of experts. For example, developing a game for national economic policy making may require economists to develop the governing rules, psychologists and educators to design the format of intermediate results, computer specialists to automate the game, etc.

The skills required for playing a game are minimal when used for training purposes only. If the game is used to generate alternative actions and forecast their effects, an experienced decision maker needs to participate.

TIME REQUIRED

The time required to develop a game depends on the complexity of the environment being simulated and on the amount of detail required. It also depends on the number of participants. Generally, a few weeks are necessary.

A typical session of game play may vary from two hours to eight or ten hours. Occasionally, games are played over a period of two or three days.

SPECIAL REQUIREMENTS

Games may be played on a digital computer (see Computer Simulation Models, CSM, page 120) so that the programmed relationships are automated. In this case, access to computer facilities, including a remote terminal, is required.

DESCRIPTION OF TOOL

REQUIRED INPUTS

Before the actual playing of the game, there are two stages of preparation:

For the design of a game:

1) Definition of the problem area, e.g., agricultural development programs.

2) Statement of the purpose, e.g., to consider the effect of alternative programs or to train area extension service agents.

3) A design team (as specified in Skills section) should be distinguished from the participating team.

For the playing of a game:

4) Specific starting values of variables.

5) Commitment from the players.

TOOL OUTPUT

Effects of alternate decisions on the simulated environment are obtained, e.g., in an agricultural program game, the "effect of distributing free fertilizers led to misuse of fertilizers and low productivity," while the "effect of increasing number of extension agents and subsidizing fertilizers led to higher productivity." This leads to a greater understanding of the complex processes described in the gaming situation.

IMPORTANT ASSUMPTIONS

Games are used with an implicit assumption that the decision makers obtain an understanding about the problem environment when they participate. This assumption is often challenged. Some educators believe that participants learn only by reacting to the changes in the simulated environment and do not try to understand the reasons for the changes. If this is true, games can have a detrimental effect on a participant's decision-making ability. However, this can be avoided by supplementing the game with lectures or literature about the problem environment.

METHOD OF USE

GENERAL PROCEDURE

1. Design the game.
   - 1.1 Identify the specific purpose of the game.
   - 1.2 Identify how a game will help meet the purposes. See if there are any games currently available that will meet the purposes (see Advantages).
   - 1.3 Identify the decision-making level of the participants. A game designed for top management may be unsuitable for supervisor-level participants.
   - 1.4 Identify the nature of decisions that a participant must make during game play.
   - 1.5 Decide how many teams the game involves and whether the game required the use of a computer.
   - 1.6 Outline a model of the environment (see Tree Diagrams, TRD, page 74; Oval Diagramming, OVD, page 81; and Interaction Matrix Diagramming, IMD, page 192). Identify important variables in the environment and establish the relationships between them in order to determine the relationship between the decisions made by the players and their effects.
   - 1.7 The time period of these relationships must be determined. This period depends on the nature of a game and the decision-making level (strategic, operational) of the participants. For example, the time period could be a week when the participants are to schedule nurses in a rural area. On the other hand, the period would be a year if the participants are to plan for national development.
   - 1.8 Determine the format and content of the intermediate results to be presented to the participant. In a computer assisted game, the intermediate results will be the computer print-out. This should be designed to provide sufficient information for participants to make further decisions and to be realistic, i.e., it provides only the type of information that can be obtained in real situations.
   - 1.9 If necessary, repeat 1.6 through 1.8 to refine details of the model. The players' instruction manual must then be written, outlining the necessary instructions for playing the game. The design of the game itself should be documented separately for subsequent review if necessary.
   - 1.10 Test the game and the instructor manual using trial sessions. This may reveal any errors in the computer program if one is used and any other limitations of the game.

2. Play the game.
   - 2.1 Introduce the participants to the simulated problem environment and familiarize them with the type of decisions they are required to make. The instruction manual for the game should cover this.
   - 2.2 Start the game session by giving initial values to the variables in the game. For example, population, men-women ratio, and fertility rate may be variables initialized in a "demographic game."
   - 2.3 Point out that the participants are required to meet some objectives during game play. Examples of objectives may be "reduce population growth to zero," and "increase per capita nutrition."
   - 2.4 Let the participants play the game.
   - 2.5 Determine the final results of the game—usually some measure of participant performance. The effectiveness of alternative decisions in meeting the objectives can be seen from the final results. These results can be used to make real decisions. The final results can also be used to evaluate the participants if the purpose of the game was training. An optional (but often useful) conclusion to the gaming exercise is to permit the participants to freely discuss the game and their participation.

EXAMPLE

Helmer and Quade describe an approach to the study of a developing economy using operational gaming (Quade and Boucher, 1968, pages 329-33). They discuss using games to analyze the processes of development and the involvement of various experts in the excercise.

Other examples of games applied in a variety of situations can be found in Helmer, 1972, and Kibee, 1961.

THEORY

Gaming is described in the literature as management games, computer simulation games, and operational games (see Quade and Boucher, 1968). Operational games at all levels are used for training as well as for assisting decision making, particularly in Defense Department applications (e.g., war games).

In industrial situations, management games are used to aid in production planning, scheduling, marketing, and long-term planning.

In the public sector, operational games are used to aid in making decisions, e.g., urban housing policies, mass transit decisions, and economic planning.

BIBLIOGRAPHY

Helmer, Olaf. "Operational Gaming." *Futures* (1972): 149-67.

Kibee, J. M.; Craft, C. J.; and Nanus, B. *Management Games*. New York: Rimhold Publishing, 1961.

Quade, E. S., and Boucher, W. I., eds. *Systems Analysis and Public Policy: Applications in Defense*. New York: American Elsevier, 1968.

VI
Accounting for Alternative Outcomes

Histograms
Subjective Probability Assessment
Decision Trees
Contingency Analysis

Project planners must deal with uncertainty. Information must be aggregated into statistics which summarize the variability of the data. The likelihood of alternative outcomes must be estimated (Subjective Probability Assessment). Two techniques are specifically structured to enable the analyst to deal with alternative outcomes or contingencies (Decision Trees and Contingency Analysis). Uncertainty is resolved in various ways, but all of the tools attempt to give a project designer a grasp on the indeterminacy and inherent variability of development processes.

Histograms

PREREQUISITE TOOLS

None.

USAGE

PURPOSE

Histograms diagram alternative outcomes which permit the inspection of characteristic patterns and the quantification of *sample statistics*.

USES

Histograms can be used to:

1) Show the frequency of the values of a *discrete variable*, such as categories of responses in a question.

2) Graph the frequency of *continuous variable* values within consecutive discrete intervals, e.g., a profile of income distribution for farmers.

3) Indicate the *range* of the variable.

4) Suggest a *central tendency* of the variable.

5) Summarize responses from a sample survey (SVY, page 36) or Delphi (DLP, page 168).

KEY DEFINITIONS

1) The *central tendency* is the most likely, or average, value of the variable.

2) A *sample statistic* is a quantitative parameter which characterizes some aspect of the population from which a set of data is drawn.

3) A *continuous variable* takes on an infinite number of values over some *range* of possible values, e.g., the temperature measured at a fixed location at different times, or measured simultaneously at various locations.

4) A *discrete variable* has only a finite number of values which are multiples of a basic unit, e.g., the numbers of members in an organization.

SHORT DESCRIPTION

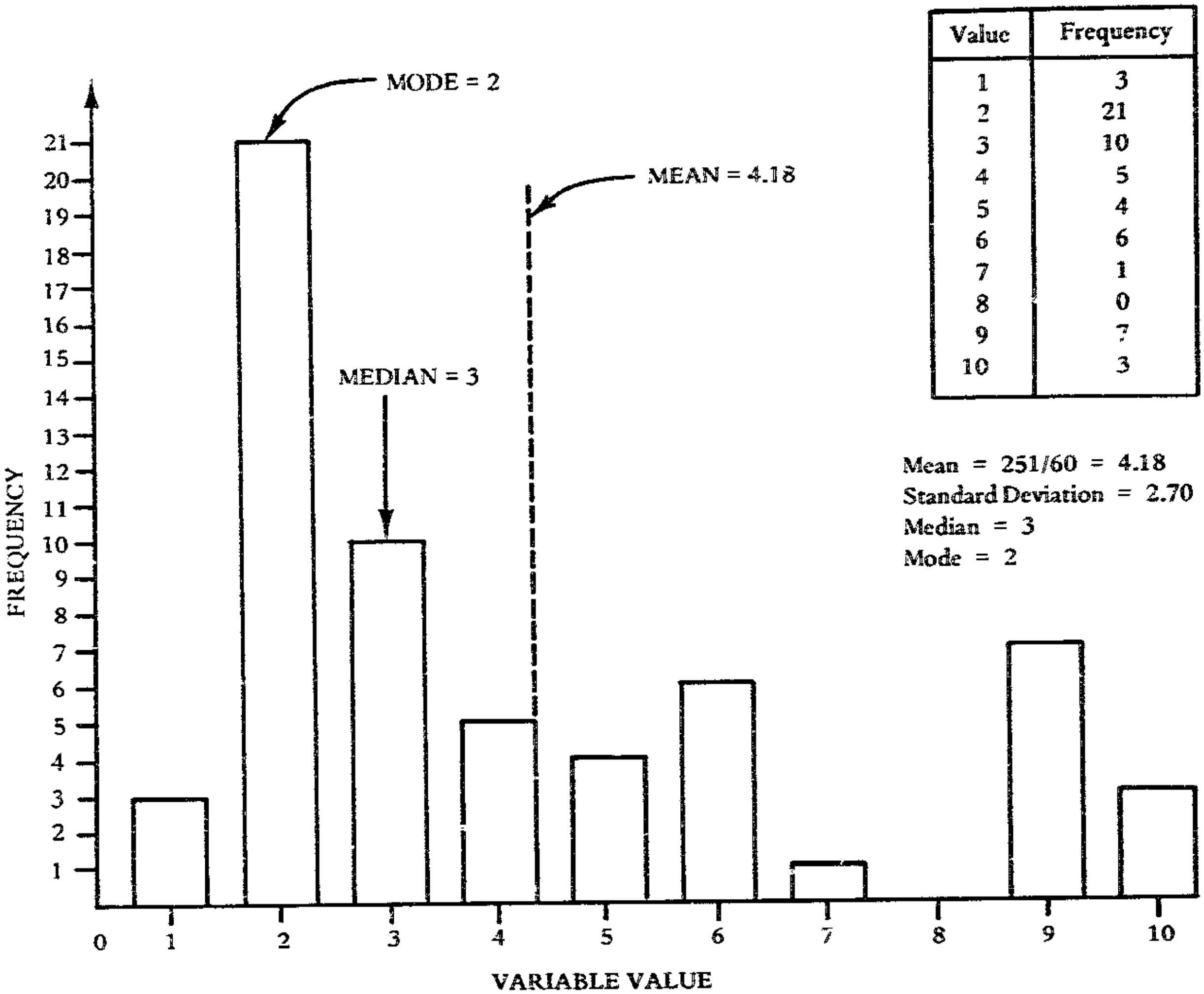
A histogram plots the frequency with which different values of a variable occur (see figure 1). If the variable is discrete, the histogram may be a series of bars centered over each value. If the variable is continuous over some fixed range or if discrete values are grouped, the histogram is a series of steps which correspond to fixed intervals of the variable.

ADVANTAGES

1) A histogram provides a clearer description of data patterns than a simple tabulation of the values. The length of the bar transforms a frequency distribution into a linear measure.

2) Sample statistics may be shown directly on the horizontal scale of the variable. Gross errors in computation can be identified by inspection.

FIGURE 1
Sample Histogram for Raw Data



Value	Frequency
1	3
2	21
3	10
4	5
5	4
6	6
7	1
8	0
9	7
10	3

LIMITATIONS

Histograms may be misleading if the observation of the frequency is over too short a time or includes too few measurements, or if the variable intervals are too large.

REQUIRED RESOURCES

LEVEL OF EFFORT

Assuming the data are at hand, the effort required is a function of the number of discrete values or intervals.

SKILL LEVEL

Judgment is necessary to mark off the scale for the variable (e.g., the range and number of intervals for a continuous variable must be specified to give the desired clarity). Computing statistics from frequency data requires simple algebra.

TIME REQUIRED

Histograms may be constructed quite rapidly, if the data are well organized.

SPECIAL REQUIREMENTS

A hand calculator speeds up computation, and many have been preprogrammed for this purpose. If data are stored on a general purpose digital computer, a frequency histogram can be generated with a minimum of complexity.

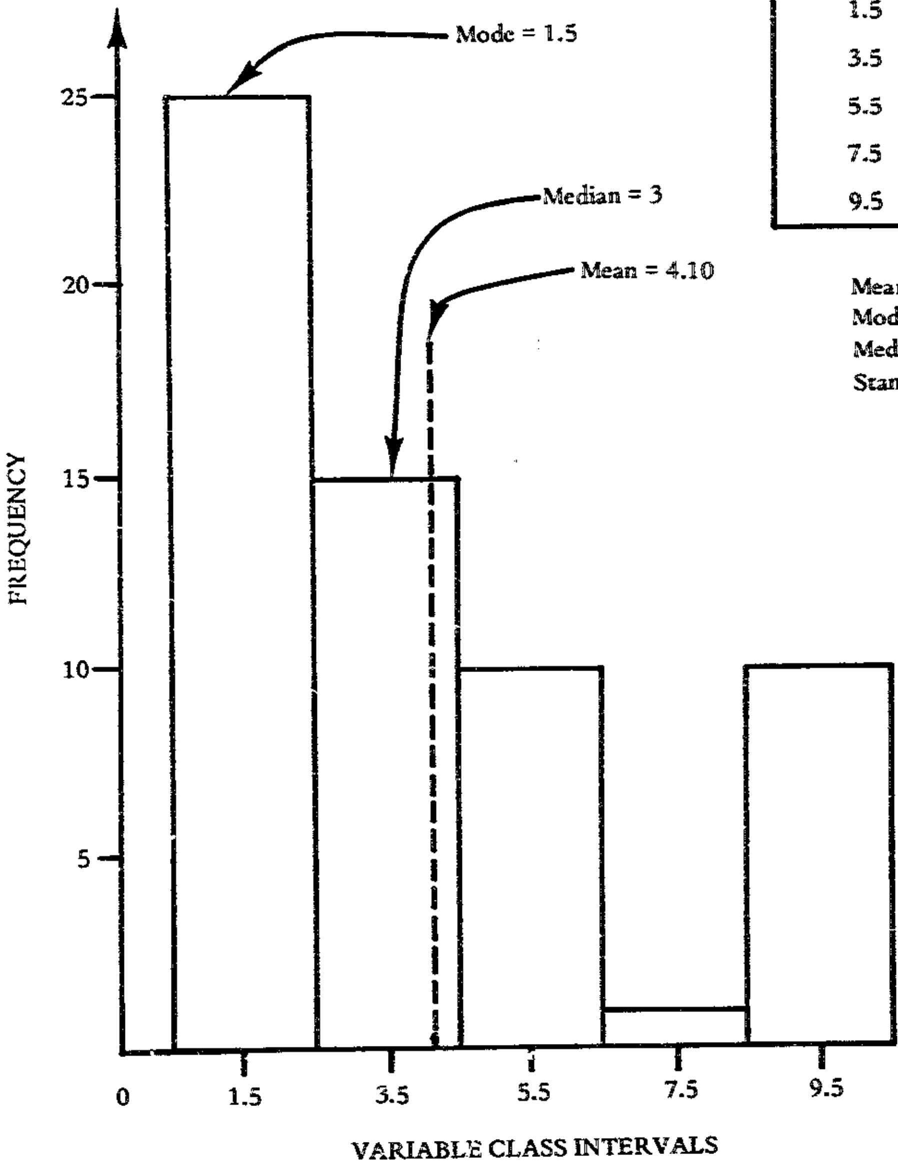
DESCRIPTION OF TOOL

SUPPLEMENTAL DEFINITIONS

1) The *mean* is the average value or central tendency of the data.

FIGURE 2
Histogram for Clustered Data

Midpoint of Class Interval	Frequency
1.5	24
3.5	15
5.5	10
7.5	1
9.5	10



Mean = 246/60 = 4.10
Mode = 1.5
Median = 3
Standard Deviation = 3.06

2) The *mode* is the value or class interval which occurs most frequently.

3) The *median* is the value corresponding to the mid-point of the data points.

4) The *standard deviation* is the measure of the dispersion of the data values about the mean.

5) A *class interval* is a uniform division of the variable range.

6) *Clustered data* are used to aggregate the data into fewer points for analysis and plotting.

REQUIRED INPUTS

The data giving the frequency distribution of discrete values of the variable are the only required input. The data may be the result of responses to a Survey (SVY, page 36) or Delphi (DLP, page 168) questionnaire. If the variable represents a qualitative judgment, then a rating scale should be used (see RTS, page 29).

TOOL OUTPUT

The technique produces a frequency histogram which may include the mean, mode, and median of the data. Together, these constitute the analysis for reporting the results of a survey or for feedback to Delphi participants.

IMPORTANT ASSUMPTIONS

Plotting measurements of a variable in a histogram is a straightforward mechanical process. Valid inferences about the general characteristics of the phenomenon represented by the variable depend on an assumption that the measurements are an adequate and unbiased sample of all possible values of the variable. For example, if the temperature at the Temasek International Airport was measured each day at noon, the resulting data would enable inferences about midday temperature at that location. However, without different data, not much could be said about temperatures at other times or at other locations.

METHOD OF USE

GENERAL PROCEDURE

Frequency Histogram for a Discrete Variable

1. Compute the range of the variable by finding the difference between the largest and smallest data values.

2. Determine the limits of the histogram's horizontal axis.

2.1 Include the range of the variable within the limits.

2.2 Mark off the units on the axis of the graph.

3. Decide if the data are to be grouped and how many groups are necessary to give the desired detail (from 8 to 25 items).

4. Determine the class interval size by dividing the range of the variable by the number of groups desired.

5. Determine the frequency distribution of variable values within each class interval and tabulate (see figure 2).

6. Determine the limits of the vertical axis.

6.1 Select an upper limit which is at least as large as the maximum frequency computed in step 5.

6.2 Select a lower limit which is either zero or the minimum frequency computed in step 5.

7. Plot the frequencies above the center of each class interval of the variable.

8. Examine the plot to determine if the histogram shows the desired degree of detail.

8.1 Expand the scale of the frequency axis if necessary.

8.2 Change the size of the class intervals to change the corresponding frequencies.

9. Finish the histogram by adding connecting bars and labels (see figure 1).

10. Compute the mean and standard deviation for raw (ungrouped) data.

10.1 Enter the data values and their respective frequencies in a table (see figure 3).

10.2 Compute the mean of the data series using equation 1, figure 3.

10.3 Compute the difference of each datum value from the mean and tabulate.

10.4 Compute the standard deviation (equation 2, figure 3).

10.5 Indicate the mean value on the horizontal axis of the histogram (see figure 1).

11. Compute the median of the data series (optional).

11.1 Order all the data points in ascending value.

11.2 Divide the number of data points by two.

11.3 Use this number to determine the corresponding data point in the ordered sequence.

FIGURE 3

Mean and Standard Deviation of Raw Data Values

Datum	Datum Value	Difference From Mean Value	Difference Squared
1 2 3			
	SUM_1 =		SUM_2 =

Mean = SUM_1/Number of data points

Standard Deviation = $\sqrt{(SUM_2/\text{Number of data points})}$

11.4 If there are an even number of data points, the median will be the average of the two data points which split the ordered sequence into two equal parts; otherwise, the median is the midpoint in the sequence.

11.5 The median value may be sketched on the histogram (note that this does not necessarily correspond to the mean value).

12. Determine and mark the mode(s) of the histogram by determining the variable value (or interval) which occurs most frequently (optional).

13. Compute the mean of grouped data.

13.1 Enter the upper and lower limits of the class intervals used for constructing the histogram (see figure 4).

13.2 Compute the midpoint of each class interval.

13.3 Compute the mean of the grouped data using equation 3, figure 4.

13.4 Indicate the mean value on the horizontal axis of the histogram (see figure 2).

14. Compute the standard deviation of grouped data.

14.1 Enter the class intervals and frequencies on a tabular worksheet (see figure 5).

14.2 Determine the origin—the class interval which contains the mean value (computed in step 13).

14.3 Determine the difference between each class interval and the origin in multiples of class intervals, e.g., ± 1, ± 2, . . . , intervals from the origin (see figure 4).

14.4 Compute the standard deviation using equation 4, figure 5. The sums are computed by completing each row of the table and then adding the appropriate columns.

Frequency Histogram for a Continuous Variable

The procedure is essentially the same as for a discrete variable except that the variable values may be in fractional multiples of a basic unit measure. The data are grouped into class intervals, and every value falling within the upper and lower values of the interval constitute one occurrence of that interval.

EXAMPLE

The examples in figures 1 and 2, while abstract, illustrate several interesting points. Figure 2 represents a clustering of the data points from figure 1 into uniform class intervals of two units each. Note the loss of detail in the shape of the histogram. The statistics for the measures of central tendency (mean, mode) change little. However, the clustering of the data values does have an effect on the standard deviation.

The use of histograms (and frequency distributions) is illustrated in Subjective Probability Assessment (SPA, page 137), Delphi (DLP, page 168), and Surveys (SVY, page 36).

THEORY

Frequency histograms are based on the concept of random variables and the theory of probability. Probability is the frequency of occurrence of a particular event—a discrete value or a value within an interval. Though this event may be random, the result of many repeated measurements generates the frequency distribution function of the random variable. It is convenient to categorize these functions into characteristic forms, e.g., the uniform distribution characterizes a variable which is equally likely to take on any value within its range. The corresponding histogram would be nearly flat.

Frequency histograms represent the distribution of a finite sample of measurements. The ability to generalize to the basic phenomenon measured is a function of sample size.

Smith (1975) gives an excellent treatment of data analysis and statistical computation. For example, saying that all response choices for a questionnaire are equally likely is the same as saying that the response histogram is uniform (flat) over the range of response. For a small sample, this is not likely to be the case.

BIBLIOGRAPHY

Smith, Kenneth F. *Statistical Survey and Analysis Handbook.* Manila, Philippines: USAID, March 1, 1975.

FIGURE 4
Mean of Grouped Data

CLASS INTERVAL				
Lower Limit	Upper Limit	Midpoint	Frequency	Midpoint X Frequency
0.5	2.49	1.5	24	36
2.5	4.49	3.5	15	52.5
4.5	6.49	5.5	10	55
6.5	8.49	7.5	1	7.5
8.5	10.49	9.5	10	9.5
			SUM_1 = 60	SUM_2 = 246

MEAN OF GROUPED DATA = SUM_2/SUM_1 = 246/60 = 4.1

FIGURE 5
Standard Deviation of Grouped Data

Midpoint of Class Interval	Frequency	Difference From Mean Class Interval	Frequency X Difference	Difference Squared	Frequency X Difference Squared
1.5	24	1	24	1	24
3.5	15	0	0	0	0
5.5	10	1	10	1	10
7.5	1	2	2	4	4
9.5	10	3	30	9	98
	SUM_1 = 60		SUM_2 = 18		SUM_3 = 128

STANDARD DEVIATION CALCULATION:*

1) $SUM_1 \div SUM_1$ = 128/60 = 2.13
2) $SUM_2 \div SUM_1$ = 18/60 = 0.3
3) Square of (2) = 0.09
4) Difference: (1— - (3) = 2.13-.09 = 2.04
5) Square root (4) = 1.43
6) Size of Class Interval = 2
7) Multiply (5) x (6) = 2 x 1.43 = 2.86

STANDARD DEVIATION = 2.86

*STANDARD DEVIATION = SIZE OF CLASS INTERVAL X $\sqrt{[(SUM_3/SUM_1) - (SUM_2/SUM_1)^2]}$ = 3.05

Subjective Probability Assessment

PREREQUISITE TOOLS

None.

USAGE

PURPOSE

Subjective probability assessment quantifies expert judgments about the chance of specific *events* occurring.

USES

Subjective probability assessment is used to:

1) Provide the *probability distributions* required for using certain techniques, such as Decision Trees (DTR, page 141).

2) Make individual judgments explicit so that they can be compared or aggregated with each other.

KEY DEFINITIONS

1) An *event* is a future outcome, the occurrence of which is uncertain, e.g., "favorable trading conditions with Temasek next year."

2) A *subjective probability* is a quantified judgment of the chance of an event occurring.

3) A *probability distribution* associates each event in the set with its probability of occurrence.

4) A *set of discrete events* consists of a finite number of mutually exclusive events. For example, the possible outcomes, or events, for casting a die would be numbered 1, 2, 3, . . . , 6; and "monsoon arrives earlier than usual," "monsoon arrives as usual," "monsoon arrives later than usual."

5) An *assessor* estimates the probability distribution of a set of events.

6) The *relative chance* reflects whether one event will occur rather than another.

7) The *ratio method* estimates probabilities for a set of events by first obtaining the relative chance of pairs of events for all possible pairs.

SHORT DESCRIPTION

Assessment of *subjective probabilities* requires the identification of a *set of discrete events.* An *assessor* then considers these events, two at a time, to determine the *relative chances* of those events occurring. This procedure is known as the *ratio method.* Simple computations then determine the probability distribution for the set of discrete events. Subjective probabilities may also be obtained for a *set of continuous events* by modifying it into a discrete set.

ADVANTAGES

1) Probability assessment makes the judgments of an individual explicit, thus allowing others to understand and respond.

2) The ratio method is easy to use because the probabilities are assessed indirectly by comparing the chances of occurrence for pairs of events.

LIMITATIONS

1) When the assessor is not motivated to perform and to think about the analyst's questions, the probabilities obtained may not be valuable. In addition, an assessor with no background in probability theory will not perform as well as one familiar with the technique.

2) When there is a large number of events, the ratio method becomes tedious. This method may also lead to inconsistencies which may be difficult to resolve.

REQUIRED RESOURCES

LEVEL OF EFFORT

After the assessor considers and gives his estimates for the relative chances of various events, the analyst performs minor computations to arrive at a probability distribution.

SKILL LEVEL

The analyst should be able to interact effectively with the assessor through skilled interviewing (IVW, page 23). An assessor with a basic understanding of probability will be better able to quantify his judgments.

TIME REQUIRED

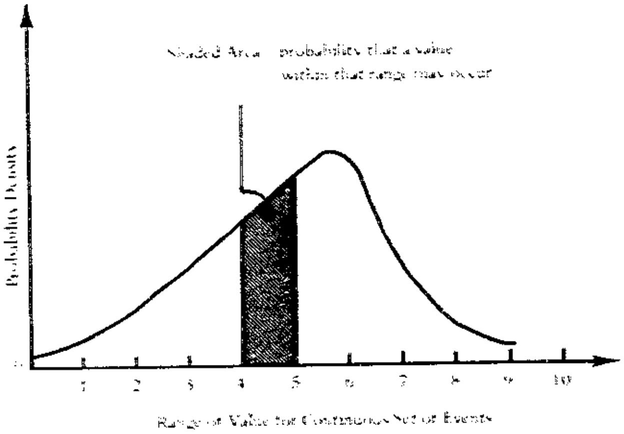
Considering a set of ten events takes about 30 minutes. The time required depends on the number of events.

DESCRIPTION OF TOOL

SUPPLEMENTAL DEFINITIONS

1) A *set of continuous events* consists of an infinite number of events. For example, the gross national product (GNP) for a coming year may range from one billion to five billion dollars and may actually be any value in that range. This may be modified by grouping the continuous events into discrete events. One event in the GNP example would be "less than two billion dollars"; another event would be "between two billion and three billion dollars," etc.

FIGURE 1
A Probability Density Function



2) A *probability density function* represents the probability distribution of a set of continuous events. The function may be expressed as a curve (see figure 1). The area under the curve for any interval of values is the probability that one of the values in that interval will occur. For example, the shaded area in figure 1 represents the probability that any value from four to five occurs.

REQUIRED INPUTS

A set of events will generally be defined by the decision maker by using a technique like the Delphi (DLP, page 168).

The events in a set may be described in quantitative or qualitative terms. A quantitative description (e.g., dollar value of exports of beef) may be classified in qualitative terms (e.g., high, medium, or low dollar exports). A qualitative description always describes a set of discrete events, whereas a quantitative description may apply to a set of discrete or to a set of continuous events.

The assessor will generally be someone whose prior experiences, knowledge, or insights are pertinent to the set of events being considered. He may be an external expert or the decision maker.

The subjective probability of a single assessor is frequently not as accurate as the aggregated estimates from several assessors. One way to improve the assessments is to have a group discussion on the questions posed by the analyst. Another way is to use a Delphi (DLP, page 168) in which the assessments of each individual are fed back to others in the group.

TOOL OUTPUT

For a set of discrete events, the output is a probability distribution. For a set of continuous events, the output is in the form of a *probability density function* (see figure 1).

For any interval of values, the area beneath the curve represents the probability that one of the values in that interval will occur. For example, the shaded area represents the probability that any value from four to five will occur.

METHOD OF USE

GENERAL PROCEDURE AND EXAMPLE

The ratio method is used to elicit probabilities for a set of discrete events.* The following steps are involved:

1. **Identify and label set of events.**
   Give each event a label, such as $x_1, x_2 \ldots, x_n$. For example, take the set of possible events: "number of tourists coming to Temasek over the next five years." Identify and label three events in the set:
   - x_1 = higher number of tourists than last five years
   - x_2 = same number of tourists as last five years
   - x_3 = lower number of tourists than last five years

2. **Assess relative chances.**
   2.1 Consider events two at a time. First, ask an assessor to estimate the relative chance for events x_1 and x_2. Then assess events x_2 and x_3, x_3 and x_4, x_4 and x_5, and so forth until all pairs up to and including x_{n-1} and x_n are covered. For the tourist example, the analyst may ask: How many times is it more likely for the event "higher number of tourists" to occur rather than the event "same number of tourists"? If the assessor answers 1.5, this is represented mathematically as:

   $$P(x_1) / P(x_2) = 3/2 \quad [1]$$

   or

   $$P(x_1) = 1.5 \times P(x_2) \quad [2]$$

   where

   $P(x_i)$ = probability of event x_i, $i = 1, \ldots, n$

   2.2 Similarly, he may assess:

   $$P(x_2) / P(x_3) = 1/2 \quad [3]$$

   or

   $$P(x_2) = 0.5 \times P(x_3) \quad [4]$$

   Continue this process for each pair of events.

3. **Examine probabilities for inconsistencies.**
   3.1 Check inconsistencies by asking the assessor to estimate the relative chance of a combination of two events which has not been assessed in step 2. For the tourist example, the assessor may be asked to estimate the relative chance of events x_1 and x_3, i.e., what is his subjective feeling for

   $$P(x_1) / (x_3)?$$

   His answer should mathematically reflect his previous answers. In checking, it is seen that:

   $$\begin{aligned} P(x_1) / P(x_3) &= [P(x_1) / P(x_2)] \times [P(x_2) / P(x_3)] \\ &= 3/2 \times 1/2 \\ &= 3/4 \end{aligned} \quad [5]$$

   or

   $$P(x_1) = 0.75 \times P(x_3)$$

   If his answer differs from 3/4, the inconsistency would have to be resolved by having the assessor re-estimate the relative chances of events x_1 and x_2, or of x_2 and x_3.

   3.2 Another method of checking inconsistencies is to directly ask the assessor to estimate the probability of an event. This is compared to the computed probabilities done in step 4.

4. **Compute the probability distribution.**
   Compute the subjective probability of each event based on the assessed ratios of the paired events. By definition, all the probabilities must sum to unity:

   $$P(x_1) + P(x_2) + P(x_3) = 1.0 \quad [6]$$

   Equations [2], [4], and [6] can then be solved simultaneously to give:

   $$P(x_1) = 1/3$$
   $$P(x_2) = 2/9$$
   $$P(x_3) = 4/9$$

   Hence, the subjective probabilities of the three events are 1/3, 2/9, and 4/9.

The assessment of a probability distribution for the continuous case is similar to the discrete case. For the continuous case, there is a range of values which may satisfy the set of events. This range is divided into intervals, and each interval is treated as an event in order to reduce the continuous case to a discrete event problem.

1. **Identify and label set of events.**
   1.1 Identify the likely range of values which the set of events may take on, e.g., the number of tourists visiting Temasek in the next five years may range from one to three million (see Rating Scales, RTS, page 29).
   1.2 Divide the likely range of values into equal intervals, the number of intervals generally being between six and eight. Values less than the lower limit of the range are intervals, as are values greater than the upper limit. Six intervals for the tourist example may be:

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*For more detail, see Winkler (1972).

less than 1 million tourists
1 to 1.5 million tourists
1.5 to 2 million tourists
2 to 2.5 million tourists
2.3 to 3 million tourists
more than 3 million tourists

1.3 Label the intervals "$x_1, x_2, \ldots, x_n$.

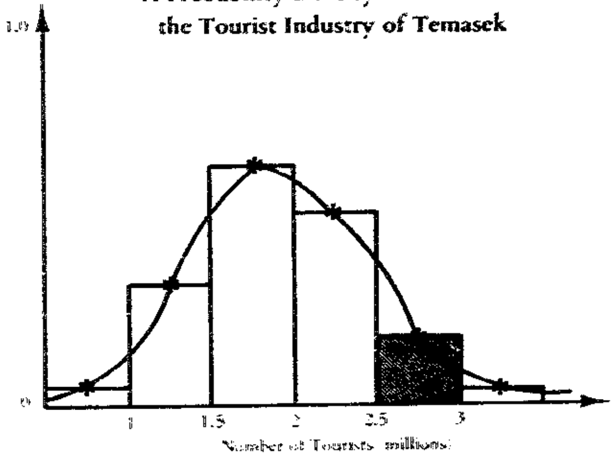
2. Assess relative changes (see discrete case, step 2).
3. Check inconsistencies (see discrete case, step 3).
4. Compute the probability distribution (see discrete case, step 4).

Keep in mind that the events for the continuous case are intervals comprising a large number of values. Plot a probability distribution in the form of a probability density function. For the tourist example, the graph may look like figure 2. Each rectangle represents the probability of occurrence for the event (or interval). Draw a curve through the mid-points of each rectangle's height for the respective intervals. This curve is approximately the probability density function for the continuous set of events being considered.

THEORY

There are several other methods of assessing subjective probabilities. Huber (1974) identifies a Variable Interval Method for a set of continuous events, as contrasted to the use of fixed intervals. Other methods involve the use of betting or wagering (Lichtenstein and Slovic, 1972: Winkler, 1972).

FIGURE 2
A Probability Density Function for the Tourist Industry of Temasek



Shaded area is equal to probability of tourists coming to Temasek.

BIBLIOGRAPHY

Huber, George P. "Methods for Quantifying Subjective Probabilities and Multi-Attribute Utilities." *Decision Sciences* 5 (July 1974): 430-58.

Lichtenstein, S., and Slovic, Paul. "Response-Induced Reversals of Preference in Gambling: An Extended Replication in Las Vegas." *Journal of Experimental Psychology* 101 (1972): 16-20.

Winkler, Robert L. *An Introduction to Bayesian Inference and Decision*. New York: Holt, Rinehart and Winston, 1972, see especially chapters 2, 3, and 4.

Decision Trees

PREREQUISITE TOOLS

None.

USAGE

PURPOSE

The decision tree technique accounts for alternative outcomes by representing and analyzing the choices of action and the expected consequences.

USES

The decision tree enables an analyst to:

1) Represent the decision situation confronting the decision maker.

2) Qualitatively assess a sequence of decisions and the chance events which may affect outcomes.

3) Compute the expected payoff values for a given sequence of decisions.

4) Determine a desired sequence of decisions according to the decision maker's criterion, e.g., maximizing payoff.

5) Determine the expected benefic by pursuing further information regarding the consequences of decision choices.

KEY DEFINITIONS

1) The *payoff values* represent the gain resulting from the occurrence of a particular action-event path.

2) An *action-event path* is the sequence of alternative actions and relevant events represented by the branches of a decision tree. Deciding to plant new seed varieties and to double crop and then having fertilizer available and an early monsoon is one action-event path in figure 1.

3) *Utility* is a quantitative expression of the worth or satisfaction associated with an outcome.

SHORT DESCRIPTION

A decision tree diagrams alternative choices available in a decision-making situation, the events which affect each alternative, and the *payoffs* that would result from making the various decisions. Sequences of decisions and events are diagrammed as successive branches on a tree graph (see figure 1). The probabilities of each event occurring are estimated and used to compute expected payoffs of various alternatives. These are used to select a sequence of decisions which maximize the probable payoff.

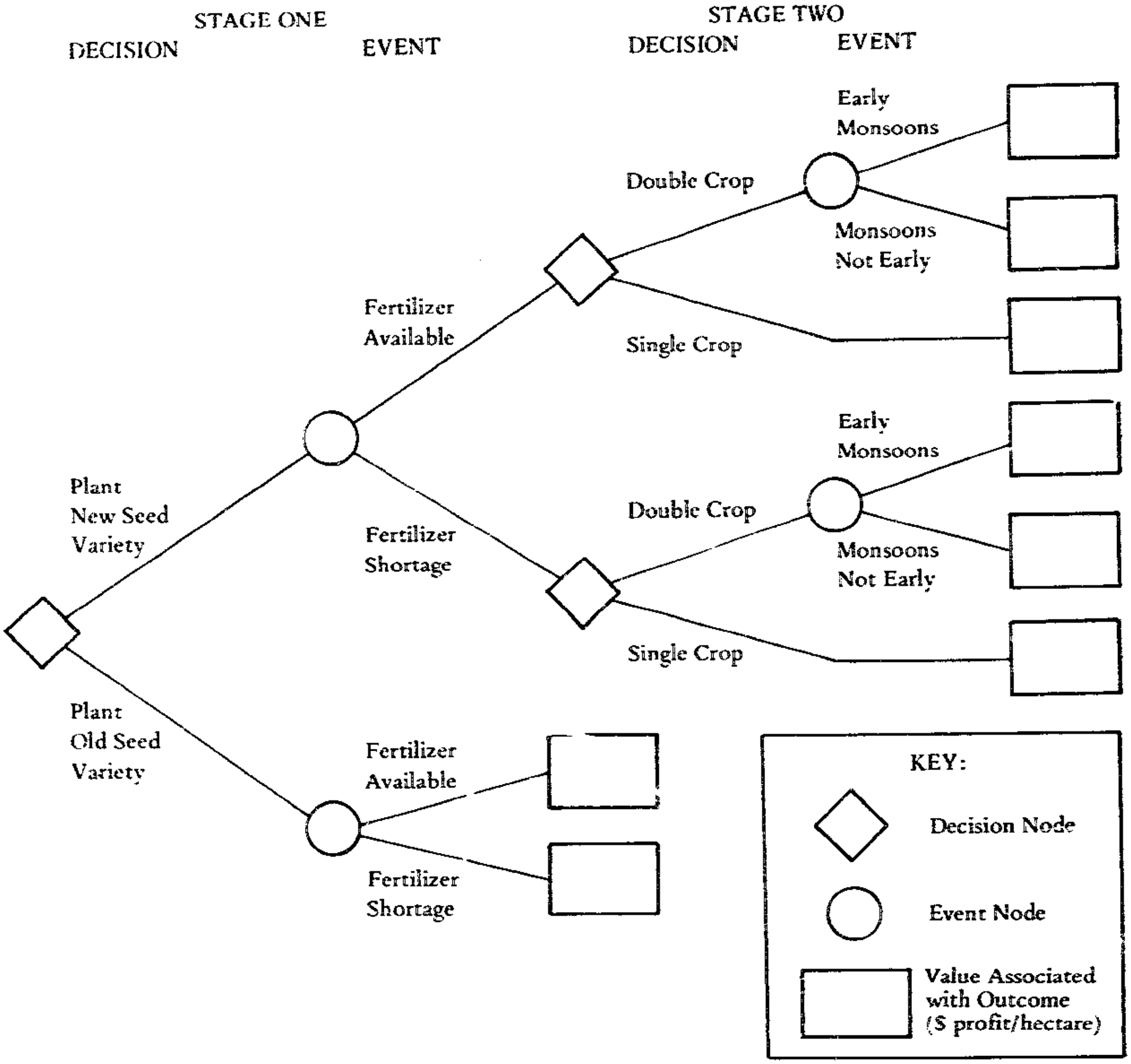
ADVANTAGES

The decision tree:

1) Forces explicit consideration of alternative actions and events which affect the actions and payoffs.

FIGURE 1

Decision Tree for Farmer with Choice of New Seed Variety and Double Cropping



2) Helps the decision maker to quantify the decision process.

3) Provides a comparison between alternatives even when absolute measures for evaluating alternatives are difficult to obtain.

4) Easily communicates a complex problem situation as a sequence of decisions.

LIMITATIONS

1) The probabilities of different future events may be difficult to obtain, thereby limiting the reliability of the decision.

2) The expected payoff may be difficult to quantify; and surrogate measures, such as utility, may have to be used (see Multiple Criteria Utility Assessment, MCU, page 32).

REQUIRED RESOURCES

SKILL LEVEL

The analysis is straightforward; but estimating probabilities and evaluating the merits of the different action-event paths require judgment. Subjective probability assessment (SPA, page 137) and multiple criteria utility assessment (MCU, page 32) may be used.

TIME REQUIRED

Obtaining the data for the analysis may require the most time—from a few hours to several months. For instance, a survey (SVY, page 36) or opinion poll may be needed to estimate the probabilities of the public accepting an innovative change.

Analysis requires an hour or less, depending on the complexity of the tree.

DESCRIPTION OF TOOL

SUPPLEMENTAL DEFINITIONS

1) *Mutually-exclusive events* are such that the occurrence of any one precludes the occurrence of the others, e.g., rolling a die (six events are possible).

2) *Collectively-exhaustive events* have the property that the sum of their individual probability of occurrence is 1.0.

3) A *contingency table* is a matrix representation of a decision involving multiple alternatives (rows) and mutually-exclusive, collectively-exhaustive states of nature (events) (see figure 2). An outcome corresponds to each intersection of an alternative and a chance state of nature (see Contingency Analysis, CGA, page 147).

REQUIRED INPUTS

The decision tree technique requires a grasp of the decision situation with regard to both the range of options and the events which affect the outcomes. The probability of each chance event must be estimated and the value associated with each outcome must be determined if the tree is to be used to select the desired decision. This may require preliminary data gathering.

TOOL OUTPUT

The decision tree provides a representation of the decision situation which, without further quantification and analysis, can be useful to decision makers. However, further analysis permits the determination of the sequence of decisions which yields the best possible outcome for a given decision criterion, e.g., maximizing payoff.

IMPORTANT ASSUMPTIONS

All the decision options can be determined a priori, i.e., no new options develop as a consequence of future events.

All events affecting the outcome of an alternative action are mutually exclusive and collectively exhaustive.

METHOD OF USE

PROCEDURE

1. **Construct the first decision-event stage.**
   1.1 Identify the decision alternatives.
   1.2 Arrange the action alternatives as the branches from a decision node (diamond) (see Tree Diagrams, TRD, page 74).
   1.3 Identify the chance events which affect the various outcomes of the decision alternatives.
   1.4 Arrange the events as branches emitting from the chance node (circle) at the end of each alternative action (see figure 2).

2. **Construct successive decision-event stages as necessary.**
   2.1 Identify subsequent decisions which may affect the outcome of the initial alternatives.
   2.2 Add these to the appropriate branch as a second stage decision (see figure 1).
   2.3 Identify events which affect the various outcomes of the second stage decision.
   2.4 Add these events as branches to complete the second stage.
   2.5 Repeat the above process for successive decisions and chance events which affect the outcomes.

3. **Determine the event probabilities necessary for analyzing the decision situation.**
   3.1 Estimate the probabilities for the occurrence of each event affecting the decision-event stages (see Subjective Probability Assessment, SPA, page 137).
   3.2 Write the probabilities on the branches corresponding to each alternative event (see figure 2).
   3.3 Verify that the probabilities for all branches emitting from any chance node sum to 1.0.

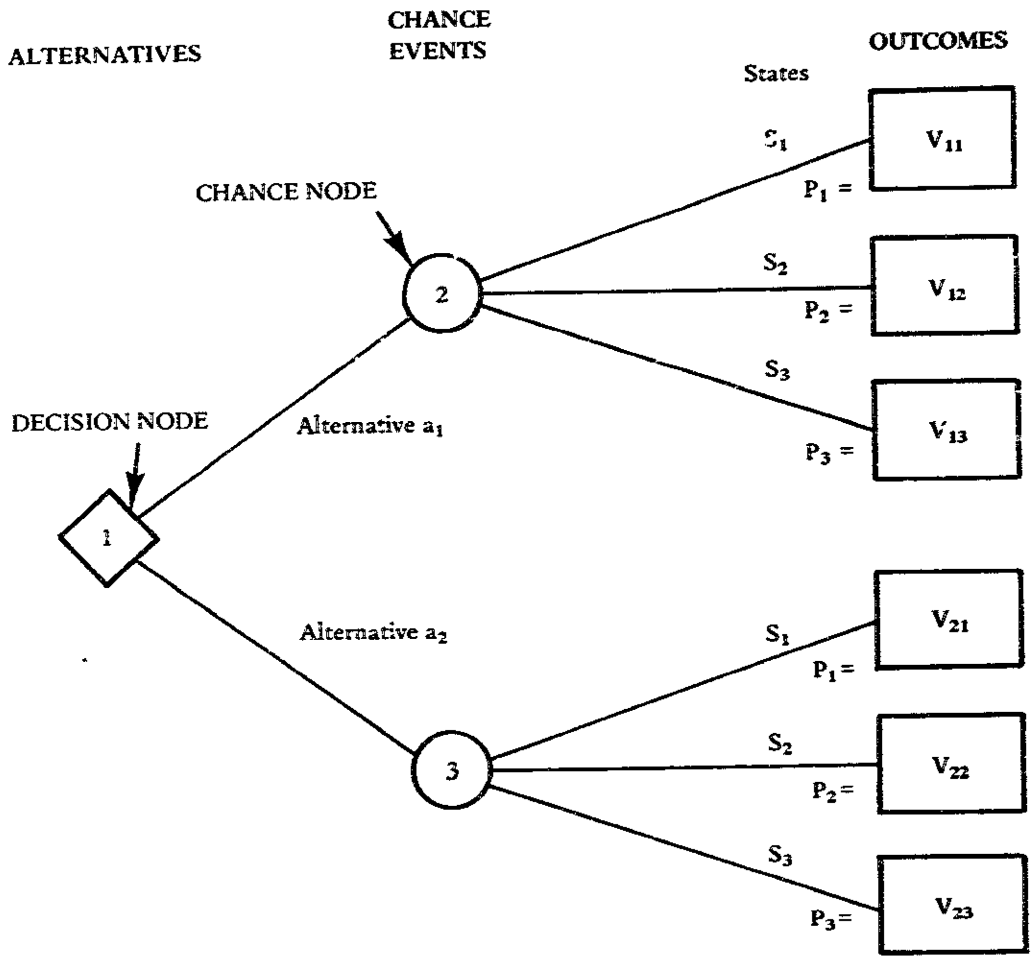
4. **Determine the payoff or utility associated with each outcome.**
   4.1 Estimate the value of each outcome which results from the occurrence of an alternative action sequence and chance events. The value may be the cost, payoff, or utility of the outcome (see Multiple Criteria Utility Assessment, MCU, page 32).
   4.2 Write the associated value in a box at the end of each tree branch (see figure 2).

5. **Determine the desired sequence of decisions.**
   5.1 Determine the criteria for selecting among alternatives:
      a) Maximizing expected payoff,
      b) Maximizing expected utility, or
      c) Minimizing expected costs.

FIGURE 2

The Decision Tree Representation of a Decision Under Risk

a) Decision Tree State



b) Corresponding Contingency Table for Single State

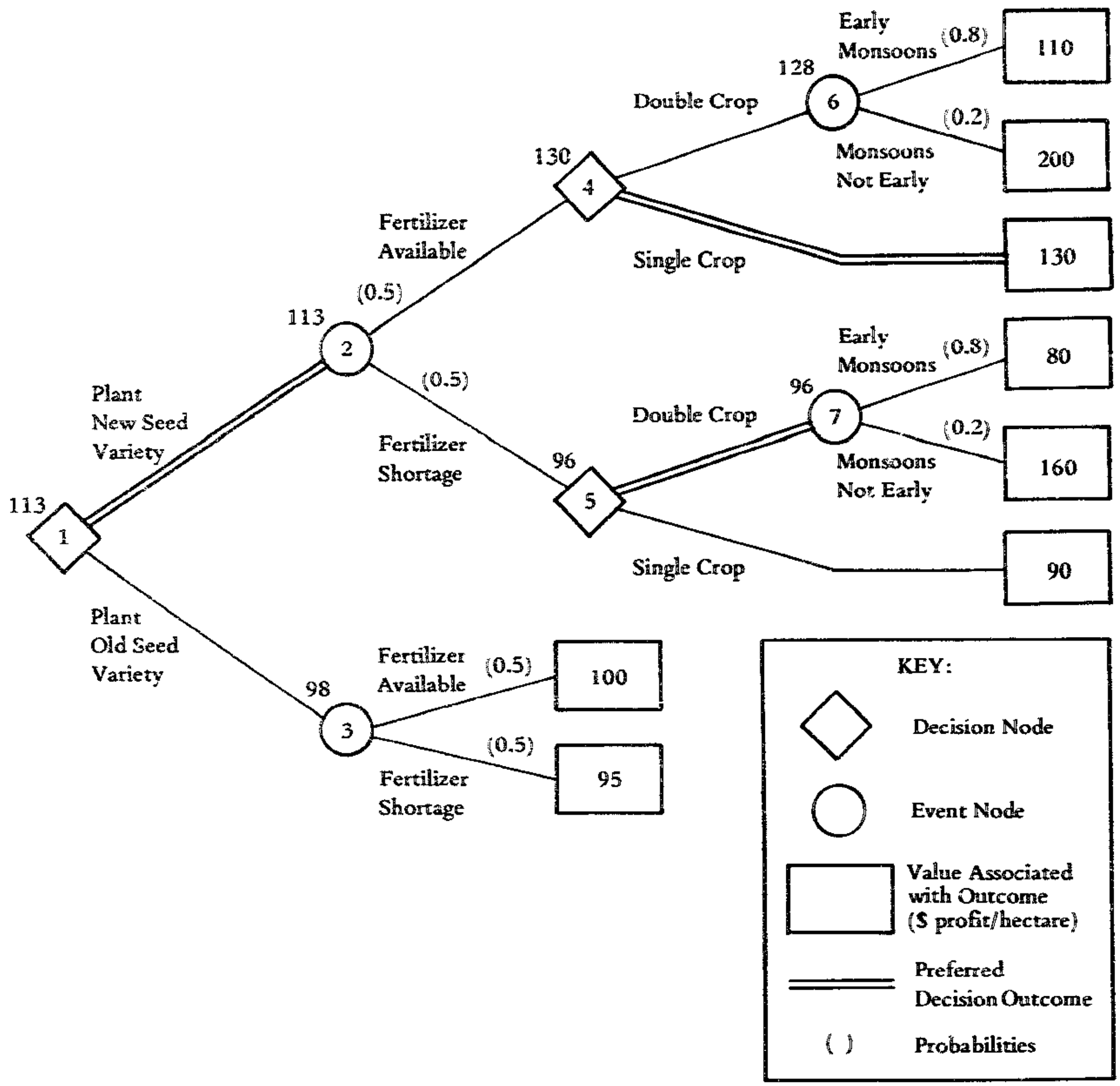
	Chance Events / States of Nature		
	S_1	S_2	S_3
Probability	P_1=	P_2=	P_3=
Alternative a_1	V_{11}	V_{12}	V_{13}
Alternative a_2	V_{21}	V_{22}	V_{23}

NOTE: Computing position values:

Node 1 = maximum (minimum) of position values for Nodes 2 and 3;

Node 3 = $P_1 \cdot V_{21} + P_2 \cdot V_{22} + P_3 \cdot V_{23}$

FIGURE 3
Analyzing the Decision Tree to Determine Maximum Expected Profit/Hectare



5.2 Beginning at the terminal decision stage (the end of the tree), compute the position value of each chance node. Sum the products formed by the probability of each event and the value associated with the outcome of the event. Write the computed total beside each node (see figure 2).

5.3 Working toward the beginning of the tree, determine the position value of each decision node. Apply the criterion to select among the values at each event node branch. For example, if the criterion is to maximize payoff or utility, then select the largest value; if the criterion is to minimize costs, then select the smallest value among the successive position values. Write the selected value adjacent to the decision node (see figure 2).

5.4 Repeat the above process for each stage of the decision tree until the position value of the first decision node has been determined. The desired sequence of decision alternatives is the marked branches in the tree.

EXAMPLE

A farmer is confronted with the following decision situation* (see figure 1):

He may plant a new seed variety which promises to increase yields, but only if fertilizer is applied at the right time. There is a 50% chance that a fertilizer shortage will arise which will nullify the benefit of planting the new variety.

The new variety has a 90-day maturation period compared to the 120 days before the old varieties can be harvested. Thus, if the monsoons are favorable, the farmer may double crop to further increase his yields (but not necessarily to double that of the single harvest output). This is risky because the chance of an early monsoon season has been forecast at 80%. The farmer risks losing not only the second crop, but overall profits are reduced by the additional planting costs.

This decision situation was diagrammed as a two-stage decision tree, and the expected profit was estimated for each outcome (see figure 3). It is not necessary to consider the double cropping choice decision if the traditional seed varieties are planted. Also, the event of an early monsoon does not affect the single crop alternative because of the shorter growing season.

*This example was inspired by Ken Smith's report, *Fertilizer Distribution Project, August-December 1972* (Phillipines Mission: United States Agency for International Development, January 1973).

Computing the desired sequence of decisions is simply a matter of working back through the tree computing the position values at each node. The position values of the chance nodes (3, 6, and 7) were computed using the expected value of the chance events, which is the sum of the products formed by multiplying the probability of the event and the estimated value associated with that outcome. For example, the position value of node 6 is:

$$E(v) = (0.8) \times (110) + (0.2) \times (200) = 128$$

This value was written by the node (see figure 2).

The position value at each decision node (1, 4, and 5) was determined from the criterion to maximize the profit. Consequently, the branch was chosen which gave the maximum expected value. The position value of node 4, for example, is 130, indicating that planting only a single crop maximizes the expected profit. However, applying the same criterion at node 5 indicates that, in the case of a fertilizer shortage, the expected profit is maximized by planting the second crop (even though early monsoons are likely). These preferred choices were indicated on the tree diagram as double lines.

The analysis indicates that planting the new seed variety is likely to be the most profitable choice. However, the decision to double crop depends on the probability of favorable monsoons.

THEORY

Decision trees are an outgrowth of statistical decision theory and probability theory (Magee, 1964). The technique is one method of dealing with decision-under-risk. The analyst attempts to account for alternative outcomes by determining the probabilities of chance events. The elements of the decision are the alternative courses of action, the possible states of nature, and the probability of each state occurring (see figure 2). The correspondence between the decision tree representation and the contingency table format should be apparent (see Contingency Analysis, CGA, page 147). DeNeufville and Stafford (1971) treat the problems in selecting a criterion and valuing the alternative outcomes.

BIBLIOGRAPHY

DeNeufville, R., and Stafford, J. *Systems Analysis for Engineers and Managers.* New York: McGraw-Hill, 1971.

Magee, J.F. "Decision Trees for Decision Making." *Harvard Business Review* (July-August, 1964): 126-38.

Contingency Analysis

PREREQUISITE TOOLS

Decision Trees, DTR, page 141.

USAGE

PURPOSE

Contingency analysis helps a decision maker choose among alternative plans designed for various contingencies.

USES

Contingency analysis is used to:

1) Inform decision makers about long-range plans.

2) Select strategies to achieve specified objectives in uncertain situations, e.g., a health delivery strategy under unknown disease conditions.

3) Choose actions when major changes in the problem environment are expected and where there is uncertainty about the nature of the change.

KEY DEFINITION

A *contingency* is a particular combination of factors that describes a future environment. For example, a contingency in agricultural planning may describe an environment where there is a large deficit in world food production, failure of monsoons for two consecutive years, a large under-nourished population, and a poor trade balance.

SHORT DESCRIPTION

Possible future states associated with a problem situation are described by contingencies. Alternative plans are developed for each contingency (see figure 1). Each plan is evaluated either qualitatively or quantitatively using techniques such as cost-effectiveness analysis (CEA, page 219). Plans are compared for a specific contingency as well as across contingencies using various criteria to simplify the analysis. A contingency table is prepared and recommendations are formulated for the decision maker.

ADVANTAGES

Much of systems analysis assumes a level of determinacy which ignores the many uncertainties involved. Contingency analysis specifically encourages planning for alternative outcomes. Consequently, the plans selected and implemented are generally more flexible than those which are developed for only one possible future state.

LIMITATIONS

There is always the danger of overlooking contingencies, partly because of the necessity of planning at one

FIGURE 1
Contingency Table with Qualitative Evaluation of Plan Performance

ALTERNATIVES	CONTINGENCIES				
	A	B	C	D	E
Plan 1	good	fair	excellent	poor	NA*
Plan 2	poor	fair	poor	NA	NA
Plan 3**	fair	good	NA	good	fair

NOTE: Plans are evaluated on a scale: very poor-poor-fair-good-excellent relative to the particular contingency.

*Plan not applicable to this contingency.

**Plan 3 was designed specifically for Contingency E.

point in time. The future situation may be shaped by the present planning decisions,* making contingency analysis an extremely complex process.

REQUIRED RESOURCES

LEVEL OF EFFORT

The effort required to develop a plan for a single future state is multiplied by the number of contingencies identified. The task of identifying contingencies and analyzing plans adds to the total effort.

SKILL LEVEL

The analyst must add foresight and intuition to his basic planning skills in order to identify alternative outcomes and account for their consequences. A multidisciplinary team brings useful skills to the task and is recommended.

TIME REQUIRED

The time needed depends on the complexity of the planning required. Time is proportional to the number of contingencies considered and the novelty of the situation.

*In this eventuality, the analyst may draw on the theory of competitive games (see Madansky, 1968).

DESCRIPTION OF TOOL

SUPPLEMENTAL DEFINITIONS

1) *Best-estimate analysis* selects the plan which was developed for the most likely contingency.

2) *Worst-case analysis* selects the plan which was developed for the most adverse contingency.

3) *A fortiori analysis* is a process of excluding alternatives which still perform badly relative to the others, even when designed for the most favorable contingency.

4) *Sensitivity analysis* is a process of varying the estimated values of selected parameters in the design to determine the sensitivity of the results to the uncertainty of the estimates.

REQUIRED INPUTS

Contingency analysis requires a grasp of the many factors which contribute to uncertainty in planning. The plans must be developed using a variety of techniques and expertise. The more points of view brought to bear on the planning process, the more likely that contingencies will not be overlooked. A multi-disciplinary team approach is preferred.

TOOL OUTPUT

Contingency analysis presents the decision maker with an array of options which reflects the analyst's understanding of future uncertainties. A plan may be recommended as a result of the analysis. The very least the decision maker can expect is an analysis of the array of contingent factors and planning assumptions (DeGreene, 1973).

IMPORTANT ASSUMPTIONS

All relevant contingencies have been identified and only these contingencies are likely to occur.

Measures of plan or system effectiveness which are appropriate for one contingency can also be applied to other contingencies.

METHOD OF USE

GENERAL PROCEDURE

1. Analyze the problems in order to determine the factors (social, technological, political, or environmental) associated with an uncertain future.

2. Identify likely combinations of factors: these contingencies describe possible futures (see Scenarios, SCN, page 164).

3. Specify alternative plans for dealing with each contingency (see IDEALS Strategy, IDL, page 231), and Program Planning Method, PPM, page 227).

4. Identify criteria for evaluating the expected effectiveness, benefits, or utility for each plan (see Cost-Effectiveness Analysis, CEA, page 219; Cost-Benefit Analysis, CBA, page 212; or Multiple Criteria Utility Assessment, MCU, page 32).

5. Considering only one contingency at a time, evaluate each alternative relative to the other alternatives and tabulate results (see figure 1) to provide a comprehensive picture of the decision parameters.

6. Apply one of the following criteria to reduce the number of contingencies:

a) *Best-estimate analysis*: Assume that all uncertain factors are determined by the analyst's best estimates. Design alternative plans accordingly.

b) *Worst-case analysis*: Assume that the most adverse contingency will occur. Design a plan (or select the alternative) for this contingency on the assumption that if it works for the worst case, it will work for the more favorable contingencies.

c) *A fortiori analysis:* Assume that all uncertainties are resolved as optimistically as possible. Design (or select) a plan for this case and compare its performance to the others. If it still performs badly, discard that alternative.

7. Use sensitivity analysis to examine assumptions and/or eliminate variables which have little influence on the expected performance of alternatives (see Cost-Effectiveness Analysis, CEA, page 219).

8. As a last resort, consider plans which either:

a) Buy time until the social, political, or technological situation changes;

b) Buy information in order to resolve some of the uncertainties affecting the decision, e.g., gather more data; or

c) Buy flexibility in design, i.e., plan systems with the capability to adapt to various contingencies.

There are additional costs associated with each of these options, but they may be the best way of dealing with the uncertainties of planning for various contingencies.

EXAMPLE

The Temasek Government wanted to develop a strategy for increasing agricultural productivity in a region populated by small-holders. A list of unknown factors was generated: the degree of cooperation among farmers, the migration rates from (or to) the region, the availability of necessary climatic and technological variables (e.g., the response of new seed varieties to unfavorable monsoon conditions).

Two contingencies were formulated and preliminary plans were sketched for each.

Contingency A

The people in the region are expected to cooperate with government efforts. There is low migration of population to urban areas. Favorable monsoons are predicted. Fertilizers are available.

Plan 1: Educate the people about the need for increased productivity, new seed varieties, and new agricultural techniques. Distribute fertilizer and encourage its use. Subsidize commercial credit.

Plan 2: Form farm cooperatives with government participation. Acquire farm machinery with the financial strength developed, using modern techniques on consolidated holdings.

Contingency B

The people in the region may be hostile to intervention and are not receptive to improved farming methods. There is migration of population to urban areas. Monsoons are expected to be erratic and poor. A fertilizer shortage is expected.

Plan 3: Nationalize productive holdings. Import labor if needed. Farm large tracts of land using mechanical farming and irrigation methods.

FIGURE 2
Contingency Table for Agricultural Strategy Planning

	Contingency A (Optimistic)	Contingency B (Pessimistic)
Plan 1: Education Strategy	10%	-5%*
Plan 2: Cooperatives Strategy	15%	4%
Plan 3: Nationalization Strategy	7%	9%
Plan 4: Incentives Strategy	2%	15%

NOTE: Effectiveness measure: Percentage increase in agricultural production for the region.
*Estimated decrease of 5% if Plan A is selected and Contingency B occurs.

Plan 4: Encourage private farming. Develop irrigation facilities and help finance. Provide incentives for farmers to immigrate from other regions if necessary.

A contingency table was prepared to represent the decision elements (see figure 2). The analysts then estimated the effectiveness of each plan using the criterion: expected percentage increase in agricultural production given a particular contingency. Analysis across contingencies followed:

Best-estimate analysis: Only plans 1 and 2 need be considered because contingency A is assumed to be the future environment. From these two, plan 2 was preferred.

Worst-case analysis: Only plans 3 and 4 were considered. Plan 4 was chosen due to the higher expected increase in production.

A fortiori analysis: Plan 1, designed for the most optimistic set of factors, was still less effective than plan 2. Therefore, plan 1 was "dominated" by plan 2 and was not considered further (although parts of the plan were considered in synthesizing a flexible, adaptive strategy).

Sensitivity analysis: Agricultural productivity estimates were found to be highly sensitive to weather conditions. Consequently, the planners decided to delay adopting a particular strategy until pilot field trials were conducted in the region. Meanwhile, a sample survey was commissioned to examine farmer attitudes on cooperation and modernization.

THEORY

Contingency analysis falls under a category of statistical decision theory identified as decision-under-uncertainty (Peston and Coddington, 1968). This situation is contrasted with models for decision-under-risk exemplified by decision tree analysis (DTR, page 141). A decision-under-uncertainty is transformed to a decision-under-risk if probabilities of each of the states of nature (contingencies) can be estimated (see Subjective Probability Assessment, SPA, page 137).

Schlesinger (1968, page 385) describes contingency planning from two different points of view. One group of planners "believe that the array and character of future contingencies can be specified in advance, and that *detailed advance planning can be done to deal with whichever one does occur* [original italics]." A second group believes "that contingencies cannot be specified precisely in advance," and that plans must be designed with the capability of adapting to unforeseen contingencies. Although the description of contingency analysis was written from the viewpoint of the first group, the complexities of development project planning strongly support the more cautious approach of the second group.

BIBLIOGRAPHY

Attaway, L.D. "Criteria and the Measurement of Effectiveness." In *Systems Analysis and Policy Planning*, edited by R.S. Quade and W.I. Boucher. New York: American Elsevier, 1968.

DeGreene, Kenyon B. *Sociotechnical Systems: Factors in Analysis, Design, and Management*. Englewood Cliffs, N.J.: Prentice-Hall, 1973, pp. 194-95.

Madansky, Albert. "Uncertainty." In *Systems Analysis and Policy Planning*, edited by R.S. Quade and W.I. Boucher. New York: American Elsevier, 1968.

Peston, Maurice, and Coddington, Alan. *Statistical Decision Theory*. CAS Occasional Paper No. 7. London: Her Majesty's Stationery Office, 1968.

Schlesinger, James R. "The Changing Environment for Systems Analysis." In *Systems Analysis and Policy Planning*, edited by E.S. Quade and W.I. Boucher. New York: American Elsevier, 1968.

VII
Forecast and Prediction

Exponential Smoothing Forecasts
Regression Forecasting
Scenarios
Delphi

The selected forecasting techniques fit into two categories. Extrapolative techniques (Exponential Smoothing Forecasts and Regression Forecasting) base forecasts of future behavior on past performance data and assumptions about the underlying processes which have generated the data. Intuitive techniques (Scenarios and Delphi) systematically combine the observations not only of past and present conditions, but predictions of future performance, constraints, and forces for change.

Exponential Smoothing Forecasts

PREREQUISITE TOOLS

None.

USAGE

PURPOSE

Exponential smoothing provides short-term forecasts of variables by extrapolating from past data.

USES

Exponential smoothing is used to:

1) Forecast demand for services or goods.
2) Obtain economic forecasts.
3) Forecast any variable where past behavior is expected to continue.
4) Provide forecasts at regular intervals.
5) Trace an underlying trend or pattern for a variable when random fluctuations in the data obscure that trend.

KEY DEFINITIONS

1) The *smoothed value* is an estimate of the average value of the variable being forecast. It is calculated each period by the equation:

$$S_t = S_{t-1} + a(x_t - S_{t-1})$$

where

S_t = the new smoothed value
S_{t-1} = the old smoothed value
a = a smoothing constant
x_t = new datum

2) The *period* of a time series is the time interval between successive observations of the underlying process. This interval may be a day, a week, a month, or one or more years. For example, the period would be a week if the datum is the weekly total of immunizations performed.

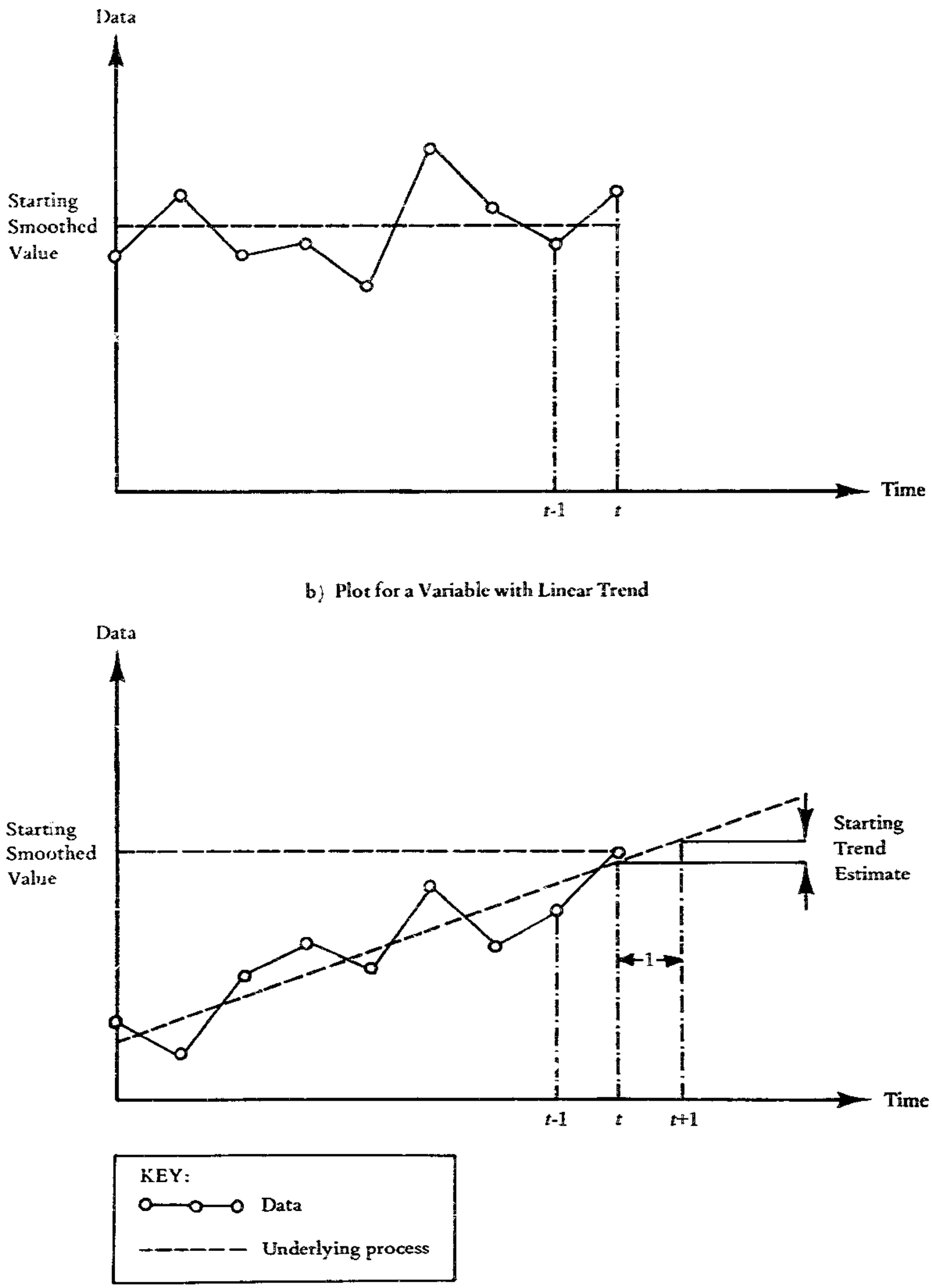
SHORT DESCRIPTION

A *smoothed value* of the average of the data is the basis for forecasting by exponential smoothing. This value is calculated for each *period* using the data for that period and the smoothed value from the previous period. The new smoothed value becomes the forecast for the next period if the average value for the variable is expected to remain constant (see figure 1a). However, variables with a steadily increasing or decreasing average (a trend) can also be forecast by obtaining a smoothed value for the average and a smoothed estimate for the trend component. The forecast for the next period is the sum of the two estimates (see figure 1b).

FIGURE 1
Plots of Past Data

a) Plot for a Variable with Constant Average

b) Plot for a Variable with Linear Trend



ADVANTAGES

1) Exponential smoothing is easy to understand and use since it relies on intuition and simple mathematics.

2) When changes occur in the behavior of the variable being forecast, exponential smoothing can continue to be used since gross errors in forecasting smooth out after a few periods.

3) Large quantities of past data need not be retained (see Regression Forecasting, RGF, page 160).

LIMITATIONS

1) Exponential smoothing is not a causal model; it only extrapolates from past data. Since past behavior only partly explains the future, exponential smoothing may not always be sufficient.

2) A more complex smoothing model is necessary to accurately forecast cyclic variations in data (see Montgomery, 1968).

REQUIRED RESOURCES

LEVEL OF EFFORT

Exponential smoothing involves the substitution of numerical values into simple formulae. The effort required is minimal.

SKILL LEVEL

Basic arithmetic skills are needed to use exponential smoothing. Some experience in choosing the *smoothing constant* is necessary to obtain good forecasts.

TIME REQUIRED

Once the smoothing constant has been selected, the forecast calculations are straightforward and require little time. It may be desirable to keep track of the errors in each forecast and take corrective action should they become too large (see Brown, 1965). This requires a minimum of extra time.

SPECIAL REQUIREMENTS

A slide rule or a calculator may be used to do the calculations. A digital computer may be desirable to forecast a large number of variables.

DESCRIPTION OF TOOL

SUPPLEMENTAL DEFINITIONS

1) The *smoothing constant* is a fraction between 0 and 1 that indicates the degree of confidence placed on the most recent datum. It is denoted by "α" in [1].

2) x_t and x_{t-1} are data values observed at time t and t-1 respectively.

3) S_t is the smoothed estimate of the average value of the variable for the time period t.

4) A_t is an estimate for the linear trend for period t.

5) T is the forecast lead time, or the number of periods into the future for which the forecast is being made.

6) α and β denote the smoothing constants whose values lie between 0 and 1.

7) x_{t-1} and x_{t+T} are forecasted estimates of the variable x calculated at time t for the next period and for T periods ahead, respectively.

REQUIRED INPUTS

Some understanding of the variable being forecast helps in estimating any trend that may be observable in past data. The data may be plotted on a graph against time (see figure 1). The variation of the data is shown in these plots. Visual inspection indicates the presence of an increasing trend in the plot shown in figure 1b.

Selecting a smoothing constant is also necessary before forecasting can be done. The function of the smoothing constant is to control the amount of importance given to the past data. The constant is greater than 0 and is usually less than 0.3. The smaller the smoothing constant, the greater is the importance given to past data, signaling confidence that the past behavior of the variable will continue. On the other hand, a large smoothing constant (but always less than 1) gives more importance to the current datum. However, a large smoothing constant may lead to large errors in the forecasts. A value of 0.2 is recommended for most applications.

Initial values for the smoothed estimates are needed before forecasting. The starting smoothed value can be taken from the plot of the past data. When the graph indicates that the data have no trend, only the smoothed value for the average needs to be estimated. This can be taken as the height of the horizontal line drawn through the data (see figure 1a). If the variable appears to follow a trend, starting values for both an average value and a trend component are required.

TOOL OUTPUT

The output is a short-term forecast of the future values of the variable. The forecast is computed from the estimate of the average value or from the estimates of the average value and the trend component, whichever is appropriate.

IMPORTANT ASSUMPTIONS

The model presented here is based on the assumption that the process which produced the behavior of the forecasted variable does not change with time. That is, the variable is assumed to have either a constant average or a constant linear trend. Higher order exponential smoothing models may be used if these assumptions are not valid for a variable (see Brown, 1965).

METHOD OF USE

GENERAL PROCEDURE

Forecasting by exponential smoothing is done in two steps:

1) Updating the smoothed values.
2) Obtaining a forecast from the smoothed values.

In the case of a variable with constant average, step 1 will be used to update the smoothed value for the average. In case of a variable with a trend, step 1 will be used to estimate the trend and the average value by smoothing.

Variable with Constant Average

1. **Update smoothed values.**
   The smoothed value for the average is obtained by the following equation:
   $$S_t = S_{t-1} + \alpha(x_t - S_{t-1}) \quad [1]$$
   The difference between the new datum and the old smoothed value gives an idea of the error in the forecast. A fraction, α, of this error is added to the old smoothed value to obtain a new smoothed value.

2. **Obtain the forecast.**
   The forecast is given by the following equation:
   $$x_{t+1} = S_t \quad [2]$$
   This equation is used since the variable is assumed to have a constant average estimated by the smoothed value and no trends. When datum for the next period, x_{t+1}, is obtained, the new smoothed value becomes the old smoothed value for the next period, and forecasting is continued by computing the smoothed value for that period. These calculations are repeated.

Variable with Trend

1. **Update smoothed values.**
   Obtain a smoothed value for the average and an estimate for the trend. The equations used for the two are similar. Equation [1] is used to estimate the average. The equation used for estimating the trend is:
   $$A_t = A_{t-1} + \beta[(S_t - S_{t-1}) - A_{t-1}] \quad [3]$$

2. **Obtain the forecast.**
   Add the trend estimate to the smoothed value that has been newly calculated. The forecast is given by the following equation:
   $$x_{t+1} = S_t + A_t \quad [4]$$
   If forecasting is to be done for more than one time period ahead, the increase (or decrease) due to the trend component needs to be accounted for. The forecast for T time periods in the future is given by:
   $$x_{t+T} = S_t + T(A_t) \quad [5]$$
   Note that in case of a variable with no trend component, the forecast for one period ahead and the forecast for many periods ahead is the same.

   As before, when a new datum is available, the new smoothed value and the trend estimate become the old smoothed value and the old trend estimate for the next period. The calculations are repeated in order to update smoothed values.

Worksheet

A worksheet can be used to facilitate the calculation of forecasts on a regular basis (see figure 2). The columns in figure 2 represent different stages in the calculation, with the forecast given in the final column and the datum given in the first column. Each row corresponds to a time period.

EXAMPLE

It is necessary to forecast the number of births in a district each month in order to procure child immunization medicine. Exponential smoothing is used to forecast the number of births. A slight increasing trend is assumed to be present in the data (see figure 2 for the calculations).

The worksheet shows that the forecast for births in February is 207. The S_{t-1} and A_{t-1} values for March can be written in the row corresponding to March.

THEORY

The basic smoothing equation in exponential smoothing is [1], which can be rewritten as:
$$S_t = \alpha(x_t) + (1 - \alpha)S_{t-1} \quad [6]$$

FIGURE 2
Work Sheet for Exponential Smoothing

	1 Data x_t	2 Old Smoothed Value S_{t-1}	3 Difference $x_t - S_{t-1}$ (1) − (2)	4 Fraction Added $\alpha\cdot$ $\alpha\cdot(3)$	5 New Smoothed Value S_t (2) + (4)	6 Old Trend Estimate T_{t-1}	7 Change in Smoothed Value $S_t - S_{t-1}$ (5) − (2)	8 Difference ($- T_{t-1}$) (7) − (6)	9 Fraction Added $\beta\cdot$( ) $\beta\cdot(8)$	10 New Trend Estimate T_t (6) + (8)	11 Forecast x_{t+1} (5) + (10)
January	205	200	5	1	201	3	1	2	.2	2.8	203.8 ≈204
February	210	201	9	1.8	202.8 ≈203	2.8	2	.8	.08	2.72 ≈2.7	205.7 ≈206
March		203				2.7					

The smoothed value for the previous time period* was given by.

$$S_{t-1} = \alpha(x_{t-1}) + (1 - \alpha) S_{t-2} \quad [7]$$

and the smoothed value for the period before is

$$S_{t-2} + \alpha (x_{t-2}) + \alpha (1 - \alpha) S_{t-3} \quad [8]$$

and so on. By repeated substitution for S_{t-1} into [6] and then for S_{t-2} into [7], we obtain:

$$S_t = \alpha (x_t) + \alpha (1 - \alpha) x_{t-1} + ... + \alpha (1 - \alpha)^n x_{t-n} \quad [9]$$

From this equation it can be seen that past data (x_{t-1}, x_{t-2}, x_{t-3}, etc.) have decreasing exponential weights. Hence the name exponential smoothing. The weights of the past data decrease with the age of the data because α is less than 1. This makes intuitive sense as more recent data are given more weight. The actual weights depend on the smoothing constant. The earlier discussion on the value of the smoothing constant follows directly from [8].

*t = present time, therefore t-1 is one time period prior, t-2 is two time periods prior, etc.

Similar formulations of exponential smoothing have been developed to forecast data that have a cyclic variation or a combination of a trend and cyclic variation. Montgomery (1968) and Brown (1965) discuss these cases at length.

BIBLIOGRAPHY

Brown, R. G. *Smoothing, Forecasting and Prediction of Time Series.* Englewood Cliffs, N.J.: Prentice-Hall, 1965.

Chambers, John C.; Mullick, Satinder K.; and Smith, Donald D. "How to Choose the Right Forecasting Technique." *Harvard Business Review* (July, August 1971): 45-74.

Montgomery, D. C. "Introduction to Short Term Forecasting." *Journal of Industrial Engineering* (October 1968): 500-03.

Regression Forecasting

PREREQUISITE TOOLS

None.

USAGE

PURPOSE

Regression forecasting obtains the relationships between two (or more) variables based on pairs (or sets) of past data values.

USES

Regression forecasting is used to:

1) Obtain economic forecasts.

2) Forecast demand for services and products.

3) Forecast any variable where past behavior is assumed to continue.

KEY DEFINITIONS

1) An *independent variable* is the non-random variable which is used for forecasting other variables using the regression. M is the independent variable in:

$$B = a + (b \times M) \quad [1]$$

where

B = number of births

M = number of marriages registered

a,b = constants

2) A *dependent variable* in regression forecasting is the variable being forecast. It is written in the regression equation as being dependent on the independent variable. For example, in [1] the dependent variable is "number of births."

3) A variable is *regressed* on another when the former is dependent on the latter. In [1], the "number of births" is regressed on the "number of marriages registered."

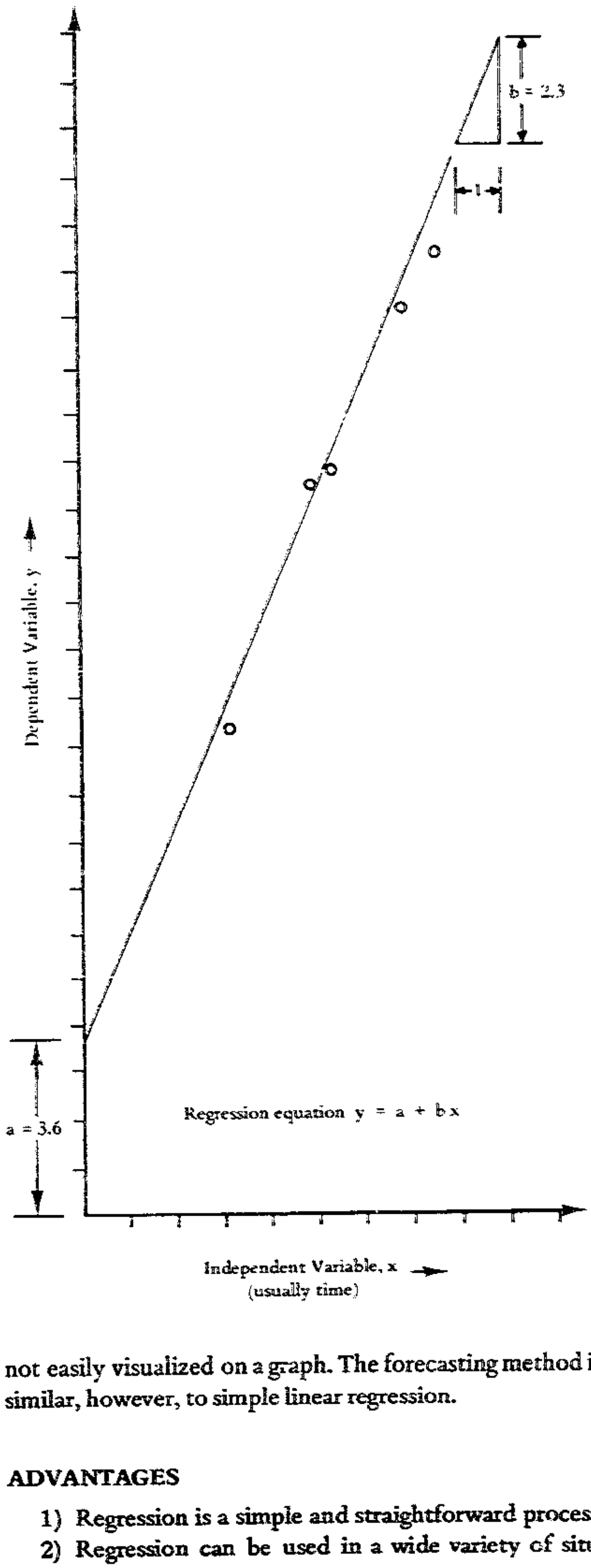
4) *Correlative behavior* is an assumed relationship between two or more variables in which the changes in one variable may be associated with predictable changes in the others. The change, however, is not necessarily cause-effect.

SHORT DESCRIPTION

Regression relates a *dependent variable* with an *independent variable* in the form of a mathematical equation. The independent variable is usually time, and regression extrapolates the past into the future. The equation is obtained from past data gathered in pairs (a value of the dependent variable corresponding to a value of the independent variable).

If the relationship is assumed to be linear, the regression of the dependent variable on the independent variable is a straight line when plotted on a graph (see figure 1). The simple linear regression equation is used to obtain forecasts of the dependent variable for a given value of the independent variable. A dependent variable may be *regressed* on two or more independent variables, but this is

FIGURE 1
Graph of Regression Line



not easily visualized on a graph. The forecasting method is similar, however, to simple linear regression.

ADVANTAGES

1) Regression is a simple and straightforward process.
2) Regression can be used in a wide variety of situations and is often the only recourse for forecasting. For example, in many social and economic contexts, causal or predictive models based on theoretical grounds are difficult to construct. Regression gives an empirical model which can be used for forecasting.

LIMITATIONS

1) Regression models estimate the correlation between variables. This *correlative behavior* is often mistaken as meaning "a change in the independent variable causes a change in the dependent variable." This may lead to false assumptions about causal relationships (see Oval Diagramming, OVD, page 81).

2) Regression forecasting extrapolates the data in order to obtain the forecasts. The relationship obtained from the data does not necessarily hold outside the range of available data, and erroneous forecasts are obtained. For example, the relationship between two variables may be linear only in the region examined and non-linear in other regions.

REQUIRED RESOURCES

LEVEL OF EFFORT

The effort required is minimal if the data for the regression model are available. However, a considerable amount of effort may be required if data collection is necessary. For example, surveys (SVY, page 36) may be needed to obtain the data.

SKILL LEVEL

Some statistical knowledge is needed to fully understand and use regression.

TIME REQUIRED

The time required to gather the data depends on the nature of the variable and the amount of data needed. Adequate regression models can be obtained using 20 to 50 pairs of data points. Once the data are obtained, the calculations require only a few hours. Regression on more than one variable takes more time depending on the number of variables being considered.

SPECIAL REQUIREMENTS

A calculator or a slide rule is useful in making the calculations.

DESCRIPTION OF TOOL

SUPPLEMENTAL DEFINITIONS

1) The *regression coefficient* is the coefficient of the independent variable in a regression equation. In [1], "b" is the regression coefficient.

2) Symbols:
x is the independent variable
y is the dependent variable
a and b are regression coefficients.

REQUIRED INPUTS

Knowledge about the variables defined in the regression equation is needed. Between 20 and 50 sets of data points are needed to obtain the regression equation. The higher the number of data sets, the higher the reliability of the regression equation.

TOOL OUTPUT

The output is the regression equation model relating the variables. The model may then be used to forecast values of the dependent variable for given values of the independent variable.

IMPORTANT ASSUMPTIONS

Regression models assume that the independent variable is deterministic (non-random) and can be measured with an accuracy that is much higher than that involved in measuring the dependent variable. Often both the variables are random, and the variable which can be measured with less error is chosen as the independent variable. However, most often observations of one variable are made at intervals of time. Time becomes the independent variable in the regression equation, and the assumption about the independent variable is then valid.

METHOD OF USE

GENERAL PROCEDURE

Linear regression fits a linear equation between the variables (see figure 1). The *regression coefficients* of the equation are selected so that the data values have minimum deviation from the line.

The following procedure is recommended to develop a regression equation.

1. **Obtain the data.**
Once the independent and dependent variables are determined, the data values are obtained in pairs, i.e., a datum point for the dependent variable corresponds to each value for the independent variable. The data should be recent and should be representative of the trend. Consider a situation where the total industrial output in a region for the next year is to be forecast. The industrial output is known to be correlated to the annual steel production. The industrial output will be regressed on the steel production. Data for past five years are used to obtain the equation (see figure 2).

2. **Determine the equation coefficients.**
If the relationship between the variables is assumed to be linear (see figure 1), the regression equation used is:

$$y = a + bx. \qquad [2]$$

The regression coefficients are calculated using:

$$b = \sum^{n} (x - x')(y - y') / \sum^{n} (x - x')^2 \qquad [3]$$

where
x', y' = averages of n data points for x and y
$\sum^{n}$ = summation of all terms in parentheses computed from data points

The calculations for [3] are easily done using a table (see figure 2b). The data points for x and y are first filled in and the averages x' and y' calculated. Using these averages, the rest of the table is filled in. The totals for columns $(x\text{-}x')$ and $(y\text{-}y')$ should be zero. This can be used as a check for calculations. The ratio of the totals in columns 5 and 6 then gives the value of b:

$$b = 26.86/11.70 = 2.29.$$

The coefficient a is calculated by

$$a = y' - bx'. \qquad [4]$$

In the example,

$$a = 16.2 - (2.29 \times 5.5) = 3.6,$$

the regression equation is

$$y = 3.6 + 2.29 \times x. \qquad [5]$$

3. **Forecast using the equation.**
The forecast of a new value of the dependent variable is made by fitting the corresponding new value for the independent variable into the equation. For example, steel production is known to be six million tons. The industrial output is estimated by substituting in [5], so that:

$$(y) = 3.6 + 2.29 \times 6 = 17.34 \qquad [6]$$

The industrial output (y) is estimated at $17.34 million using the linear regression equation.

EXAMPLE

Many examples of regression analysis may be found in the literature. Fredericks' (1976) analysis of cooperative

FIGURE 2
Regression Computation

a) Data for Forecasting Industrial Output

Year	1970	1971	1972	1973	1974
Steel Production/yr (million of tons)	7.5	6.8	3.1	5.2	4.9
Industrial Output/yr (millions of $)	20.3	19.2	10.3	15.8	15.6

b) Table for Computing Regression Coefficients

	(1) x	(2) y	(3) x - x′	(4) y - y′	(5) (x - x′)(y - y′)	(6) (x - x′)²
	7.5	20.3	2.2	4.1	8.2	4.0
	6.8	19.2	1.3	3.0	3.9	1.69
	3.1	10.3	-2.4	-5.9	14.16	5.76
	5.2	15.8	-0.3	-0.4	.12	.09
	4.9	15.4	-0.6	-0.8	.48	.36
TOTALS	27.5	81.0	0.0	0.0	26.86	11.70
AVERAGES	x′ = 5.5	y′ = 16.2	0.0	0.0	$b = \frac{26.86}{11.70} = 2.29$	

moveme its in West Malaysia is illustrative and instructive. Twelve structural variables were included in the analysis of structural development.

Bedworth (1973) has an excellent presentation of regression forecasting when the independent variable is time.

THEORY

Regression equation models are widely treated in statistics texts (Fryer 1966, or Wetherill 1972). The theory is based on summing the squares of the deviation of each data point from the corresponding value of the model, and then selecting coefficients of the model which minimize this sum. If the model equation is a straight line, the coefficients fit a linear regression model. Non-linear regression models are used to fit equation coefficients to data which do not appear to fall on a straight line.

Multiple regression models use the same basic principle to fit the observed data to two or more independent variables. The forecaster is referred to specialized texts (Draper, 1966) for details.

BIBLIOGRAPHY

Bedworth. D. D. *Industrial Systems.* New York: Ronald Press Company, 1973, pp. 84-113.

Draper, N. R., and Smith, H. *Applied Regression Analysis.* New York: John Wiley and Sons, 1966.

Fredericks, L.J. "A Trend Analysis of the Structure of the Cooperative Movement in West Malaysia, 1922-1967." *Cooperative Information*, ILO, January 1976.

Fryer, H. C. *Concepts and Methods of Experimental Statistics.* Boston: Allyn and Bacon, 1966.

Wetherill, G. Barne. *Elementary Statistical Methods.* London: Chapman and Hall, 1972.

Scenarios

PREREQUISITE TOOLS

None.

USAGE

PURPOSE

A scenario forecasts the future state(s) of a *system* based upon assumptions about interactions and external conditions.

USES

Scenarios may be employed to:

1) Identify and clarify major issues for debate among policy makers and interest groups.

2) Formulate a narrative for dynamic behavior of a social system, e.g., for interpreting Oval Diagramming (OVD, page 81).

3) Provide the input for techniques such as Gaming (GAM, page 124).

4) Provide a framework for normative forecasts of desired future conditions.

KEY DEFINITIONS

1) A *system* is a collection of components which interact to achieve a common function.

2) A *state scenario* describes conditions and events (the state of the system and the external context) at a single future point in time.

3) A *transient scenario* forecasts the changes in and the alternative actions on a system at various stages in the evolution of the system.

SHORT DESCRIPTION

A scenario is a narrative forecast of the future states of a system. It is developed from a description of the present conditions and an extrapolated forecast of future conditions. The forecast is based on the external constraints to change, and the likely interactions between system variables in the progression from current conditions to some future state.

A scenario may be either a *state scenario* for a single point in the future or a *transient scenario* tracing the evolution of the system over time.

ADVANTAGES

1) Scenarios help illuminate the interaction of psychological, social, economic, cultural, political, and military dimensions in a form that permits understanding many such interactions at once. They are especially useful for policy decisions.

2) Kahn and Wiener (1967) argue that scenarios call attention to the larger range of possibilities that must be considered in the analysis of the future.

3) Scenarios help stimulate and discipline the imagination.

4) Scenarios generally have an illustrative and pedagogical value for the decision maker.

LIMITATIONS

1) It is a formidable task to take into account and successfully predict the interplay of the various dimensions (e.g., social, political).

2) Scenarios suffer from uniqueness: they represent only the views of those experts who constructed them, and there is no guarantee that the future is accurately predicted.

REQUIRED RESOURCES

LEVEL OF EFFORT

The decision maker and the analyst collaboratively define the subject of the scenario. The analyst identifies, organizes, and interacts with a group of experts to understand the present system and to construct the scenarios.

SKILL LEVEL

The analyst and experts should be able to identify the major dimensions and attributes of the present system in order to identify new developments and understand their character and significance.

TIME REQUIRED

The time required depends on the complexity of the system being studied and the time span of the scenario. The analyst and the experts may spend several days constructing from three to five different scenarios which describe the same general situation.

DESCRIPTION OF TOOL

SUPPLEMENTAL DEFINITIONS

1) The *dimensions* of a system are collections of its attributes, where each collection represents a major aspect of the system, e.g., political, economic, social, or psychological.

2) The *attributes* of a system include the elements or components of the system and the interrelationships among them.

3) A *goal* is a value judgment which satisfies one or more human needs, e.g., "to promote equality in schooling."

4) A *driving force* is an attribute of a system which causes changes in the system state over time.

5) The *base system state* is the set of current conditions which describe the essential characteristics of the scenario. It is denoted by $S(t)$, where t is the present time.

6) An *intermediate image*, $S(t + n)$, describes the state of the system after a time interval n.

7) The *external context* represents the constraints on the base system.

REQUIRED INPUTS

Scenario construction requires prior agreement on the kind of scenario (either trend or state), the subject of the scenario, and the time span to be included.

The subject of the scenario is generally a system or sector of a country or region, e.g., the tourist industry or the energy situation for the country of Temasek or the social structure of a river basin population.

The time span varies according to the importance of the system under consideration. The time span of the scenario, for most situations, should cover at least 15 years to project beyond characteristics of the present situation. Future images become increasingly blurred as the time span is extended, effectively limiting a scenario to 30 years.

The analyst may wish to assemble a group of experts, each familiar with a major dimension of the system, though the scenario may be developed using a Delphi (DLP, page 168).

TOOL OUTPUT

The scenario technique generates a narrative description of the future state(s) of the system. The format is the *base system state* description and one or more *intermediate images*, together with a description of the *external context* and the *driving forces* behind the forecasted changes (see figure 1).

One or more scenarios may be constructed:

1) Several alternative state scenarios for a single point in time, or

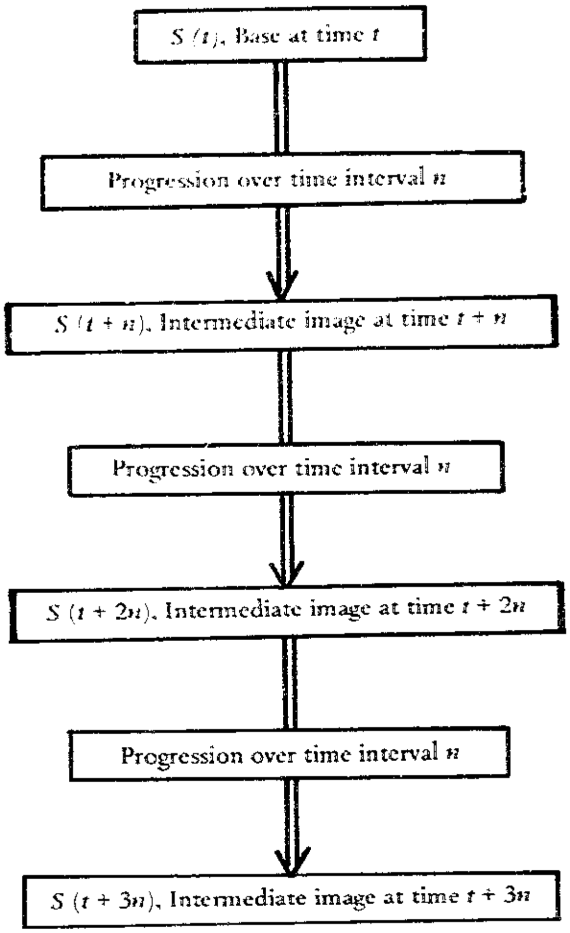
2) One (or perhaps two) transient scenarios which forecast the effects of different policies on the evolution of system conditions.

These scenarios may be compared and contrasted for review by decision makers and interested parties.

IMPORTANT ASSUMPTIONS

A scenario is constructed by extrapolating future conditions from present conditions and foreseeable driving

FIGURE 1
A Standard Format for a Scenario



forces for change. Consequently, a fundamental assumption concerning dynamic system behavior is implied: a system exhibits current conditions which are the result of all the previous current and prior forces on the system. However, social systems are self-organizing and anticipatory, and the current system state may be influenced by anticipated future conditions. Accounting for these factors in scenario construction requires that the analyst be aware of the possible effect of anticipated actions on the future state of the system.

METHOD OF USE

GENERAL PROCEDURE

The following steps describe the development of a transient scenario and are based on the work of Durand (1972) and Gerardin (1973):

1. **Construct the base system state.**
   1.1 Identify the major subgroups in the base system.
   1.2 Identify the attributes of the subgroups.
   1.3 Choose one of the attributes as the driving force for change in the system.

2. **Identify the external context.**
   2.1 Formulate hypotheses about the constraints on change in the base system state.
   2.2 Consider constraints which may change during the time span of the system.

3. **Develop the progression to the first intermediate image.**
   3.1 Identify any trends in the interaction between attributes of the base system for time interval n, where n is typically 5-10 years.
   3.2 Identify any changes in the external constraints for time interval n.
   3.3 If alternative or competing trends are likely, construct an intermediate image at time $t + n$ for each major trend.

4. **Construct the intermediate image.**
   4.1 Using the dimensions and attributes identified in step 1, describe the likely system state or conditions at time $t + n$.
   4.2 Take into account the forces for change, the external constraints, and the trends internal to the system.

5. **Repeat steps 3 and 4 until the desired time span has been covered.**
   5.1 The last intermediate image becomes the new base system state.
   5.2 To progress to the next intermediate image, consider changes for the interval from time $t + n$ to time $t + 2n$, etc.
   5.3 End the scenario with the last intermediate image.

If a normative scenario is being developed, the procedure in step 4 is inverted. Instead of predicting the intermediate image, the analyst tries to identify the alternative actions or policies that are necessary to achieve a desired system state. This is typically an iterative process, where first one set of policies, the internal trends of the system and the external context, are used to forecast a likely progression. The discrepancy with the normative system state is then used to indicate alternative policies until the desired and the predicted intermediate image merge.

EXAMPLE

A scenario was developed for the cattle industry in the country of Temasek. The goal was "to improve the quality of life for all Temasekians." Two criteria indicate achievement of this goal: a decrease of nutritional deficiencies among the population, and an increase in foreign exchange.

The *base system state* was described:

> Four subgroups have been identified: the herdsman, the middlemen, the meat-packing industry and the consumers of beef. The herdsmen are generally nomadic and own 90 percent of the cattle in Temasek. Cattle breeding and feeding practices are inefficient. The nomads have a strong emotional attachment to their cattle as they equate the ownership of cattle with prestige.
>
> The herdsmen sell their cattle to middlemen. The cattle reaches consumers after going through several levels of middlemen, thus inflating the price of beef.
>
> The meat-packing industry is small at present but is owned by a big multi-national company. The beef is packed mainly for export. . . .

The attributes of the subgroups were the value system of each subgroup, the economic linkages between the subgroups, and major institutions. The meat-packing industry was selected as the driving force for the scenario because it wanted to increase its growth rate.

The *external context* may be described as:

> There will be maintenance of favorable trading conditions with the developed countries. No adverse weather conditions will occur. . . .

Starting with the base and external context, the progression was formulated to give the following scenario:

> It is the year 1977. The demand for beef in developed countries is seen to increase greatly over the next seven years. To meet this demand a multi-national company invests 20 million dollars in a meat-packing plant geared for both domestic and overseas consumption of beef.
>
> Educational efforts are carried out to make the herdsmen settle and learn better cattle breeding and feeding practices. This will ensure a regular supply of beef for the meat-packing plant. There is considerable resentment by the herdsmen. Since only a few herdsmen react positively to the efforts, the herdsmen are not allowed to graze on land wherever or whenever they wish thus forcing them to settle.
>
> By 1982 the meat-packing plant has been established and most herdsmen have reluctantly settled. The multi-national company pays the herdsmen high prices for their cattle. The middlemen find themselves being forced out of their traditional supply links. The middlemen, who handle many foodstuffs other than beef, organize into a cohesive unit and in 1985 go on strike. There is mass hoarding of food by housewives and prices increase remarkably. The military is asked to provide trucks for the transportation of essential foodstuffs. . . .

Several such scenarios were formulated for review and evaluation by the decision maker.

THEORY

Scenarios are constructed based on a planning philosophy which might be called "futures-creative" (Gerardin, 1973). Scenarios are effective decision aids if the decision maker accepts such a planning philosophy. A future is to be designed which is in line with stated goals. A future will not be accepted if it is simply an extrapolation or extension of past events.

Scenarios have been used widely and are especially useful for policy making. Kahn and Wiener (1967) constructed scenarios for international political systems. Durand (1972) and Gerardin (1973) recorded several applications in France, including regional development planning. Kraemer (1973) cites a study in urban planning. Brown (1968) describes political scenarios done at the Department of Defense.

BIBLIOGRAPHY

Brown, Seyom. "Scenarios in Systems Analysis." In *Systems Analysis and Policy Planning: Applications in Defense*, edited by E. S. Quade and W.I. Boucher. New York: American Elsevier, 1968.

Durand, Jacques. "A New Method for Constructing Scenarios." *Futures* (December 1972): 325-30.

Gerardin, Lucien. "Study of Alternative Futures: A Scenario Writing Method." In *A Guide to Practical Technological Forecasting*, edited by James R. Bright and Milton E.F. Schoeman. Englewood Cliffs, N.J.: Prentice-Hall, 1973, pp. 276-88.

Kahn, Herman, and Wiener, Anthony J. *The Year 2000: A Framework for Speculation on the Next Thirty-Three Years*. New York: Macmillan, 1967.

Kraemer, Kenneth L. *Policy Analysis in Local Government: A Systems Approach to Decision Making*. Washington, D.C.: International City Management Association, 1973, pp. 128-32.

Delphi

PREREQUISITE TOOLS

None.

USAGE

PURPOSE

The Delphi is a group process technique for eliciting, collating, and generally directing informed (expert) judgment towards a consensus on a particular topic.

USES

The Delphi may be used in:

1) Establishing goals and their priorities.

2) Identifying the dimensions and the attributes of a problem.

3) Providing forecasts (e.g., identifying future developments and their effects).

4) Clarifying positions and delineating differences between group members.

5) Gathering information from a group whose members do not meet face-to-face (either by choice or practicality) and wish to retain their anonymity.

SHORT DESCRIPTION

The Delphi is a method whereby individuals are allowed to focus on and debate issues anonymously. The study is typically conducted by mail through several rounds of questionnaires (QTN, page 19). The results of each round are collected, collated, and analyzed by a design team. Based on this analysis, questions for the subsequent round are developed. The Delphi generally promotes convergence of opinions, although it may provide the basis for disagreement.

ADVANTAGES

1) The anonymity provided by the Delphi precludes some undesirable aspects of face-to-face communication, such as dominance by certain personalities and inhibition of expression.

2) A Delphi participant may respond with opinions which more truly represent his or her feelings.

3) Individuals who may not otherwise afford the time required for a group meeting may participate.

4) With the Delphi, a large heterogeneous group can participate on an equal basis.

5) The Delphi is obviously useful when the respondents are geographically scattered.

LIMITATIONS

1) The Delphi is precluded when there is a limited time available to aggregate participants' judgments, because of the delay in gathering and assimilating responses.

2) The Delphi should not be used with individuals who have difficulty reading or expressing themselves in written communication.

3) High participant interest and commitment is assumed or the quantity and quality of responses decreases with successive rounds.

4) Desirable features of a group meeting, such as instant communication and intellectual stimulation, are compromised.

REQUIRED RESOURCES

LEVEL OF EFFORT

The design team will have to spend a significant amount of time designing questionnaires and analyzing completed questionnaires. Integration between the decision maker and Delphi design team is necessary to ensure that the goals or requirements of the decision maker are understood by the design team.

SKILL LEVEL

The design team must be able to establish unbiased questionnaire designs which relate the Delphi exercise to its purpose (see QTN, page 19). The feedback of comments and reactions to the respondents should be succinct and representative without reflecting the bias of the design team. Members of the design team who are knowledgeable in the subject matter greatly facilitate this crucial process.

TIME REQUIRED

Approximately six weeks are required to complete a Delphi exercise which consists of four rounds of questionnaires (see figure 1). Since eight days are allowed for each set of responses (including three days for *dunning*), the Delphi requires only about two weeks of actual effort.

The continual motivation of the respondents is important in order to get a quick response and good return percentage. Consequently, the design team needs to minimize the delay between receipt of questionnaires and transmittal of the next one to participants. Analysis of the returned questionnaires and design of the subsequent questionnaires should begin immediately rather than waiting until the expected return for each round.

DESCRIPTION OF TOOL

DEFINITIONS

1) *Dunning* is the process of recontacting participants who have failed to return their questionnaires.

2) A *target group* is a set of persons with certain common characteristics, e.g., all experts possessing knowledge about a particular problem, or farmers with land in the same river basin.

REQUIRED INPUTS

Since Delphi is a tool to aid decision making, it will be most effective if the decision maker is involved throughout the process.

Respondents should be con..dered who:

1) Have special experience or knowledge to share;
2) Represent a cross-section of opinions; and
3) Can be motivated to participate.

The size of the design team will vary from two to five, in direct proportion to the size of the respondent group. Delbecq, et al. (1975) found that, in their experience, 30 well-chosen respondents were sufficient: few additional ideas were generated by having more participants. About 15% of the selected participants will decline.

For the questionnaire to communicate successfully, the questions should:

1) Be as short as possible.

2) Be adapted to the language most familiar to the respondent's area of expertise (e.g., health or education).

3) Elicit useful responses at the level of abstraction required (i.e., general vs. specific).

TOOL OUTPUT

The output of the Delphi exercise will generally be a convergence of opinion.

One type of output may be a frequency distribution or histogram of forecasts (see HIS, page 131). For example, the respondents may estimate what the legal minimum wage should be for the country of Temasek in 1980 in order to ensure adequate housing and food for citizens. The frequency distribution graph in figure 2 indicates that an interval of $75 to $100 was favored by most respondents as the desirable minimum wage. It also shows that a great majority of the respondents would not set a minimum wage below $75. The mean and standard deviation may be computed for the responses and added to the graph (HIS, page 131).

Another type of output is the ranking of responses to a particular question. For example, the respondents may list the problems they perceive in the health field. The output is a vote on the importance of the problems.

METHOD OF USE

GENERAL PROCEDURE

Delbecq, et al. (1975) recommend that the following steps be followed in designing and implementing a Delphi exercise. This procedure is only one way in which a Delphi exercise may be carried out. The number of rounds of

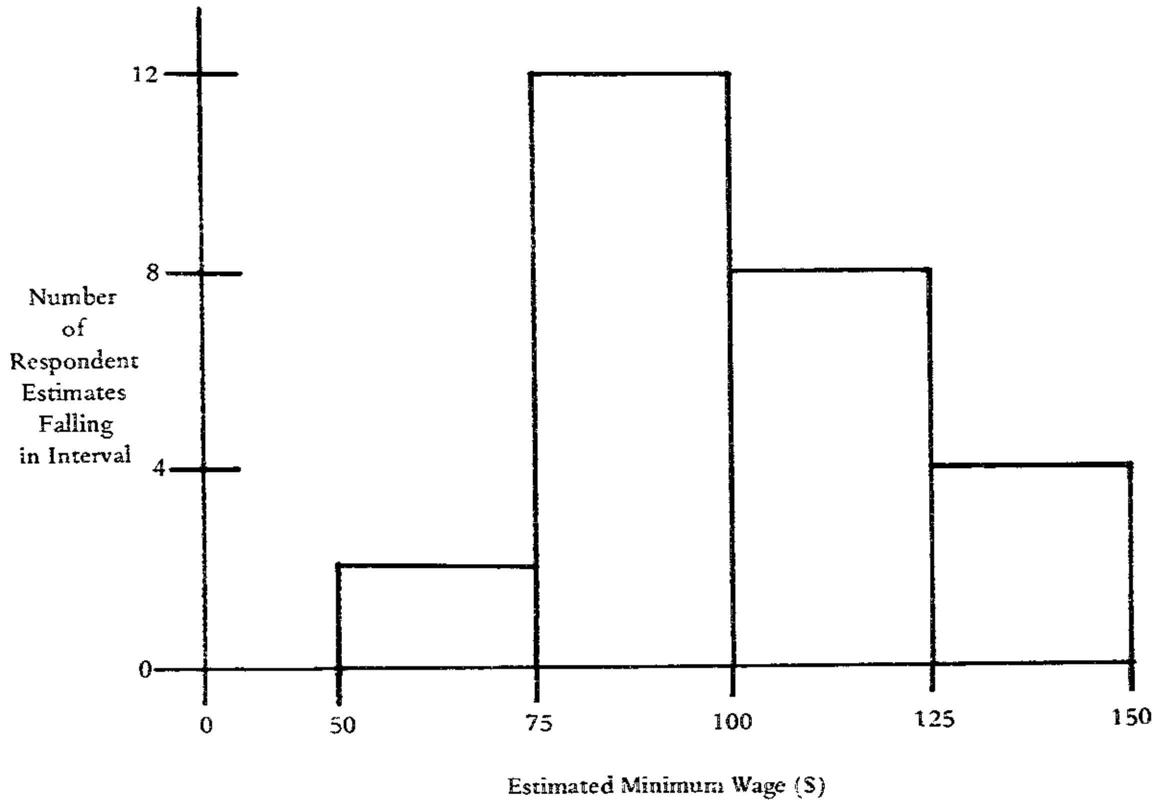
FIGURE 1
Schedule for Delphi

Activities	Minimum Time Required	
1. Develop problem statement	½ day	one day
2. Select respondents	½ day	
3. Contact respondents	2 days	
4. Develop questionnaire #1 and test	½ day	
5. Type and send out	1 day	
6. Response time	5 days	
7. Dunning time (if used)	3 days	
8. Analysis of questionnaire #1	½ day	two days
9. Develop questionnaire #2 and test	½ day	
10. Type and send out	1 day	
11. Response time	5 days	
12. Dunning time (if used)	3 days	
13. Analysis of questionnaire #2	½ day	two days
14. Develop questionnaire #3 and test	½ day	
15. Type and send out	1 day	
16. Response time	5 days	
17. Dunning time (if used)	3 days	
18. Analysis of questionnaire #3	½ day	two days
19. Develop questionnaire #4 and test	½ day	
20. Type and send out	1 day	
21. Response time	5 days	
22. Dunning time (if used)	3 days	
23. Analysis of questionnaire #4	1 day	
24. Prepare report	1 day	
25. Type report and send out	1 day	
26. Prepare respondents' report	½ day	
27. Type report and send out	1 day	

The minimum time is 47 days, allowing 8 days (including dunning) for each response.

SOURCE: Andre Delbecq et al., *Group Techniques for Program Planning: A Guide to Nominal Group and Delphi* (Chicago, Ill.: Scott Foresman, 1975), p. 87.

FIGURE 2
Frequency Distribution of Estimates of Minimum Wage



questionnaires, the types of questions, the responses required, and the analyses performed will vary depending on the type of application and the actual situation.

1. Determine the basis for a Delphi.
   1.1 A statement of objectives or problems is developed by the decision maker in cooperation with the rest of the design team.
   1.2 Target groups of respondents (e.g., agricultural economists, engineers, planners, etc. in an agricultural development exercise) are generated by the design team. Names of potential respondents are then identified.
   1.3 Telephone or personal contact is made with the potential respondent. The respondent is informed of the objectives of the Delphi, the nature of the respondent group, the obligations involved, how long the Delphi will take, how the Delphi works, and how his or her participation will be mutually advantageous. The safeguards on anonymity may be explained.

2. Design questionnaire #1.
   2.1 The initial task of the respondents is generally to generate a list of items. Examples of such items would be barriers to delivery of services, perceived problems, or potential developments.
   2.2 The design team formulates questions which are consistent with the statement of objectives (see Questionnaires, QTN, page 19).
   2.3 A short cover letter outlines the task and reiterates the agreement reached in the initial contact with the respondent in step 1.

3. Solicit responses for questionnaire #1.
   3.1 If possible, the questionnaire is pretested to ensure that questions are not misinterpreted. The group may be composed of several typical respondents from the Delphi group.
   3.2 The questionnaire and cover letter are distributed to all respondents. Return of the completed questionnaires should be prearranged (e.g., by enclosing self-addressed stamped envelopes).
   3.3 If sufficient questionnaires are not returned by the specified date, dunning, or carefully composed reminders, should be directed to the Delphi group. A response rate of 85% is usually considered acceptable.

4. **Analyze questionnaire #1.**
   - 4.1 Responses are copied and cut into slips so that each member of the design team has a set for each question. For example, for the question, "What agricultural developments do you foresee for Temasek in the next 15 years?" the slips may read "more effective fertilizers," "lining of irrigation ditches with concrete," etc.
   - 4.2 Each member sorts the response items for all questions into stacks representing similar responses to a question. The stacks are then labeled, e.g., for agricultural development, "Irrigation," "Education," "Technology."
   - 4.3 A member of the team reads his stack of labels. Through group discussion, the design team agrees upon categories of responses.
   - 4.4 Response slips are reordered according to the category labels. Obvious duplications are eliminated, and closely related items are combined. Statements expressing the resulting items within each stack are formulated. The result of this effort constitutes the list of items for questionnaire #2.

5. **Design questionnaire #2.**
   - 5.1 Questionnaire #2 should help respondents understand, clarify, criticize, and support items identified in questionnaire #1.
   - 5.2 Several things may be asked of the respondent. He may be asked to forecast when a development may take place or if the items identify potential future developments. He may be asked to identify what impacts such a development might have, or he may be asked to vote on the items. The respondent is encouraged to provide comments, e.g., he may state why he thinks a problem is important.
   - 5.3 If the respondent is to vote on the items, the rank-order procedure may be used (see Nominal Group Technique, NGT, page 14).

6. **Solicit responses for questionnaire #2.**
   Repeat step 3, including pretest and dunning (if necessary).

7. **Analyze questionnaire #2.**
   - 7.1 The comments for each item are placed in stacks (see step 4) to be summarized and communicated to the respondent in questionnaire #3.
   - 7.2 If voting has taken place, the results are aggregated and the items are ranked according to their votes. If quantitative forecasts have been made, a frequency distribution is constructed (see figure 2) and distributed to the respondents in the next questionnaire (see Histograms, HIS, page 131).
   - 7.3 The responses are reviewed to see if they are useful in achieving the objectives set up in step 1. If necessary, the next questionnaire can be altered by encouraging a different kind of comment or by making responses more specific.

8. **Design questionnaire #3.**
   - 8.1 This questionnaire aims to explore disagreements identified in questionnaire #2.
   - 8.2 The results of step 7—the ranking of the items, the aggregated forecasts, and the summarized comments—are given to the respondents.
   - 8.3 The cover letter informs the respondents that they should react to any questions and criticisms and should lobby for or against items they feel strongly about.

9. **Solicit responses for questionnaire #3.**
   Repeat step 3, though a pretest is seldom necessary.

10. **Analyze questionnaire #3.**
    The design team reviews the reactions to the comments and summarizes them in a procedure similar to that outlined in step 4.

11. **Design questionnaire #4 (optional).**
    - 11.1 This is a final attempt towards consensus.
    - 11.2 Questionnaire #4 is similar to #3 except that it also provides a summary of respondents' reactions.
    - 11.3 The respondents consider the final reactions and are asked to provide a vote or quantitative forecast similar to that indicated in questionnaire #2.

12. **Solicit responses to questionnaire #4 (optional).**
    Repeat step 3, omitting the pretest.

13. **Analyze questionnaire #4 (optional).**
    The rankings are totaled for each item to identify its importance. Where forecasts were made, final frequency distributions are constructed.

14. **Closure.**
    The participants are informed of the results to provide a sense of closure.

EXAMPLE

In dealing with a country's economy, the decision maker determines that continued inflation is a major problem. To combat the problem, he must identify the factors causing inflation and its effects. Target groups may be economists, corporation heads, consumer advocates, trade union leaders, and agricultural experts.

Questionnaire #1 asks, "What are the factors which may contribute to inflation over the next five years?" The respondents answer by listing several items they feel are important:

Increase price of oil
Strengthen border defenses
Shortage of rice

Questionnaire #2 lists all the responses, and each respondent provides comments and votes by giving each item a numerical value which corresponds to the importance of that item.

Item	Vote	Comments
Increase price of oil	3	If new sources of oil are found, price increase may be less
Strengthen defenses on border	0	High likelihood of military aid from another country
Shortage of rice	4	Import prices and number of tons of rice imported will increase

The responses for questionnaire #2 are analyzed. The votes are aggregated and comments are summarized. Questionnaire #3 asks for reactions to the aggregated votes and comments. One respondent's reaction may be:

Item	Vote	Comment	Reaction
Strengthen defenses on border	153	High likelihood of military aid from another country	The other country failed to support our country last year despite previous pledges

Questionnaire #4 then circulates all reactions and asks for a final vote.

THEORY

A number of theoretical arguments have been made to support the claim that the Delphi method is superior to conventional uses of groups in problem solving or forecasting. In 1964, Gordon and Helmer laid the foundations for the Delphi. Delbecq, et al. (1975) compared the characteristics and performances of interacting, nominal, and Delphi groups. Dalkey (1969) provided empirical arguments for the relative accuracy of Delphi estimates compared to individual or face-to-face group estimates.

BIBLIOGRAPHY

Dalkey, N. "An Experimental Study of Group Opinion." *Futures* 1 (June 1969): 282-88.

Delbecq, Andre; van de Ven, Andrew; and Gustafson, David. *Group Techniques for Program Planning: A Guide to Nominal Group and Delphi*. Chicago, Ill.: Scott Foresman, 1975.

Gordon, Theodore J., and Helmer, Olaf. *Report on a Long-Range Forecasting Study*. Rand Paper P-2982. Santa Monica, Calif.: Rand Corporation, September 1964.

Helmer, Olaf; Gordon, Theodore J.; Enzer, Selwyn; de Brigard, Raul; and Rochber, Richard. *Development of Long-Range Forecasting Methods for Connecticut: A Summary*. IFF Report R-5. Middletown, Conn.: The Institute for the Future, September 1969.

Martino, Joseph P. *Technological Forecasting for Decisionmaking*. New York: American Elsevier, 1972, pp. 18-64.

VIII
Analyzing Projects

Cash Flow Analysis
Discounting
Net Present Worth
Benefit-Cost Ratio
Internal Rate of Return
Impact-Incidence Matrix
Cost-Benefit Analysis
Cost-Effectiveness Analysis

The financial and economic analysis of projects requires the synthesis of many techniques. The primary process is the weighing of project benefits against the costs (Cost-Benefit Analysis). The time stream of benefits and costs must be considered (Cash Flow Analysis) and weighted (Discounting) in order to make project alternatives comparable. Distribution effects are an essential factor in a systems approach to economic analysis (Impact-Incidence Matrix). Various criteria are used to decide the merits of projects (Net Present Worth, Benefit-Cost Ratio, and Internal Rate of Return).

The effectiveness of projects (or systems) is weighed against costs (Cost-Effectiveness Analysis) to evaluate the degree to which various alternatives achieve given objectives. This is a criterion not unlike those used for analyzing benefit-costs, except that benefits are not valued in monetary units.

Cash Flow Analysis

PREREQUISITE TOOLS

None.

USAGE

PURPOSE

Cash flow analysis determines the difference between the *incremental costs* and the *incremental benefits* for each year of a project in order to evaluate its financial viability.

USES

Analyzing cash flows:

1) Provides an overall picture of the costs and benefits accruing from a project over the estimated life of the project.

2) Enables calculation of the *total cash flow* or the *net incremental benefit* of the project.

3) Indicates any negative cash flow years which may affect project viability.

4) Provides the basis for calculating measures which account for the time value of money (e.g., Net Present Worth, NPW, page 188; Benefit-Cost Ratio, BCR, page 194; and Internal Rate of Return, IRR, page 200).

KEY DEFINITIONS

1) *Incremental costs and benefits* are computed by subtracting the "without project" values from the "with project" values. They represent the changes the project is expected to produce compared to what would otherwise occur. Note that this is not the same as computing "before" and "after" project values, since conditions may be predicted to change whether or not the project is implemented (see Sirken, or Gittinger, 1972).

2) *Annual cash flow* is the net incremental "benefits" for each year of a project and the difference between the incremental benefits and costs.

3) *Total cash flow* is the sum of annual cash flows for the life of the project. It is an undiscounted measure* of the aggregate change expected from implementing a project.

4) *Financial analysis* is done from the viewpoint of the individual, group, or business which will directly gain or lose because of the project. All costs and benefits are valued at market prices.

5) *Economic analysis* is done from the viewpoint of the national government and the economy. Taxes, interest, custom duties, etc., are excluded from the calculation of costs and benefits, and labor and foreign exchange may be shadow-priced.

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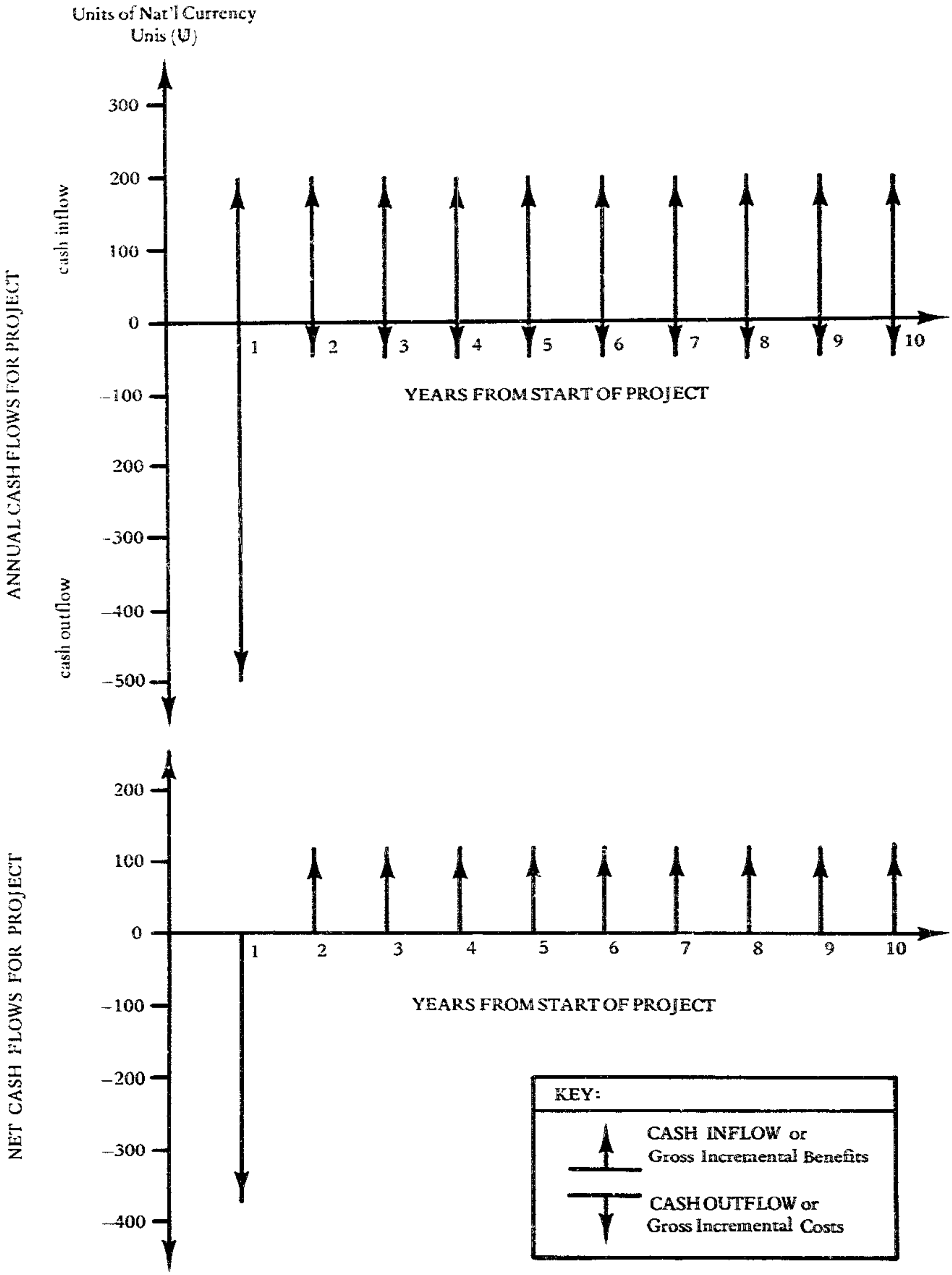
*In contrast to net present worth or other discounted measures (see DIS, page 184).

FIGURE 1
Graphic Illustration of Cash Flow for a Project



6) *Shadow prices* are adjusted market prices which reflect the true benefit or cost to the economy, e.g., the difference between the market (subsidized) price of fertilizer and the world price the government must pay.

SHORT DESCRIPTION

Cash flow analysis is a central part of the financial and economic evaluation of projects. Distinguishing between "with project" and "without project" benefits gives the incremental benefit (Gittinger, 1972) and the changes in benefits that are projected during each year of the project. Incremental costs are computed using the same distinction.

The *annual cash flow* is the difference between incremental benefits and incremental costs in that year. A typical project has an early negative and a later positive cash flow when the incremental benefits exceed incremental costs (see figure 1).

Cash flow analysis for development projects distinguishes between *financial* and *economic* analysis (see Cost-Benefit Analysis, CBA, page 212). This distinction affects the identification and estimation of project costs and benefits. Otherwise, the subsequent computation procedure is the same.

ADVANTAGES

Cash flow analysis shows the changes that the project is expected to bring about in both increased benefits and increased costs. There may be changes in the amounts of benefits or costs as well as in the sources (USDA, 1971). The project may replace an existing service or production arrangement whose costs and benefits represent the "without project" financial situation.

The total cash flow for a project gives an indication of the performance of a project during its life.

A negative annual cash flow may indicate financing problems for the project, and credit may need to be arranged.

LIMITATIONS

The annual cash flow of a project is an aggregated measure of the complex interaction among gross benefits and costs from "with project" and "without project" estimates. As a consequence, many assumptions about individual project-induced changes in the environment may be lost in the aggregate data.

The total cash flow for a project fails to account for the time value of money. Cash flow analysis does not account for benefits or costs which cannot be assigned a monetary value (e.g., good will, customer confidence, or a farmer's sense of security).

REQUIRED RESOURCES

LEVEL OF EFFORT

Cash flow analysis demands extensive data gathering and forecasting of costs and benefits. These tasks should not be underestimated, particularly since cash flow analysis is usually the first step in a sequence leading to an analysis of the economic and financial feasibility of a project.

SKILL LEVEL

Skills in cash accounting, balanced by the ability to judge future disbursements, are essential. If data are available, the subsequent computations are rather mechanical. But at all times the meaning behind the figures must temper their use. This is undoubtedly a skill which must be learned from analyzing related projects in similar environments.

TIME REQUIRED

Several days to several weeks may be required for data gathering. A longer period is necessary if a survey is involved (SVY, page 36). The analysis should not require more than a few hours.

SPECIAL REQUIREMENTS

Budgetary data and computation devices (e.g., hand calculators) are useful.

DESCRIPTION OF TOOL

REQUIRED INPUTS

Cash flow analysis requires an estimation of costs and benefits over the life of a project. Where accounting information is available and reliable, the determination of capital and operating costs and projected profits is straightforward. However, the indirect costs and benefits which may not be easily derived require considerable astuteness and information-gathering.

TOOL OUTPUT

Cash flow analysis gives a pattern of benefits and costs which can be analyzed directly to influence investment decisions (figure 1). For example, if a cash flow in any year is negative, the project may have to be redesigned or credit may have to be provided. Typically, however, the data will be used to compute other criteria of economic feasibility, e.g., the Net Present Worth (NPW, page 188) and the Benefit-Cost Ratio (BCR, page 194).

FIGURE 2
Small Farmer Tractor Utilization: Purchase Option

	YEARS FROM START OF PROJECT										
	1	2	3	4	5	6	7	8	9	10	TOTAL
WITHOUT PROJECT Gross Costs	Units (₡) (Temasek National Currency)										
Usual Production Expenses	100	100	100	100	100	100	100	100	100	100	1000
Gross Benefits	160	160	160	160	160	160	160	160	160	160	1600
Net Benefits (Annual Profit)	60	60	60	60	60	60	60	60	60	60	600
WITH PROJECT Gross Costs											
Investment Costs (tractor)	500	0	0	0	0	0	0	0	0	0	500
Production Expenses											
Usual Expenses	130	130	130	130	130	130	130	130	130	130	1300
Operating and maintenance of tractor	50	50	50	50	50	50	50	50	50	50	500
Gross Benefits	360	360	360	360	360	360	360	360	360	360	3600
Net Benefits (Annual profit)	(320)	180	180	180	180	180	180	180	180	180	1300
CHANGES DUE TO PROJECT											
Incremental Costs (Cash outflow)	580	80	80	80	80	80	80	80	80	80	1300
Incremental Benefits (Cash inflow)	200	200	200	200	200	200	200	200	200	200	2000
Net Incremental Benefits (Project annual cash flow)	(380)	120	120	120	120	120	120	120	120	120	700
	TOTAL CASH FLOW = ₡ 700										

IMPORTANT ASSUMPTIONS

It is assumed that the relevant costs and benefits have been identified and quantified in monetary units. Where this is impossible, the cash flow analysis gives only an abbreviated picture of an investment decision. Other measures, such as Cost-Effectiveness Analysis (CEA, page 219), must then be used.

METHOD OF USE

GENERAL PROCEDURE

1. **Identify the cost and benefit components of the project. Identify the target population—the people who are to directly benefit from the investment or project (see Impact-Incidence Matrix, IPX, page [illegible]7).**
   1.1 List the costs which will be changed as a result of the project. These include changes in the costs of goods, services, labor, and management identified by contrasting the "with project" and the "without project" situation. The "without project" costs are zero if the investment is not replacing a current practice or productive enterprise.
   1.2 List the categories of benefits which will be changed as a result of the project. Increased production efficiency, higher yields, and more marketable products contrast "with project" benefits with the "without project" benefits.
   1.3 If the cash flow analysis is part of a financial analysis of the project, identify the costs and benefits which affect the individual, cooperative group, enterprise, or target population. These include taxes, the subsidized prices of inputs, and the prevailing market prices for yields.
   1.4 If the cash flow analysis is part of an economic analysis, identify the costs and benefits for the target population which represent a return or cost to the whole society. Taxes are excluded,* and the unsubsidized price of inputs and the world prices of exportable produce are used. Shadow prices must be determined for imported goods and labor (see Gittinger, 1972).

2. **Determine the life of the project or the time span of analysis.**
   2.1 Estimate the effective life of any major capital equipment, e.g., tractors, pumps, buildings.
   2.2 Estimate the probable time span for the full realization of benefits.
   2.3 Select a project life based on these estimates and the knowledge that costs or benefits occurring in more than 20 years have little effect on criteria such as net present worth. The discounted values (see Discounting, DIS, page 184) are small in relation to values in the first decade of a project.

3. **Estimate the gross costs and benefits during each project year.**
   3.1 Estimate all quantifiable costs and benefits projected for each project year and enter in a table (see figure 2). These are the "with project" values. A convenient accounting convention is to assume that all costs and benefits are paid at the end of the year in which they occur.
   3.2 Estimate the "without project" costs and benefits which will hypothetically occur if the current situation continues in the absence of any investment project. It may be necessary to conduct a survey to determine the average costs and benefits accruing from current practices of the target population (see Surveys, SVY, page 36). Enter these estimates in the table (see figure 2).

4. **Compute the incremental costs and benefits of the project for each year.**
   4.1 Subtract the "without project" benefits from the "with project" benefits to give the incremental benefits for each project year and enter in the table as a change due to the project.
   4.2 Subtract the gross "without project" costs from the gross "with project" costs to give the incremental costs for each project year and enter in the table as a change due to the project.

5. **Compute the annual cash flows or net incremental benefits.**
   5.1 Compute the annual cash flows by subtracting the incremental costs from the incremental benefits to give the net incremental benefit.
   5.2 Compute the total cash flow for the life of the project by summing the annual cash flows. The computations in steps 4 and 5 are illustrated in figure 3.

6. **Diagram the annual cash flows (optional).**
   6.1 Plot the incremental costs (cash outflow) and benefits (cash inflow) (see figure 1).
   6.2 Plot the net incremental benefits (annual cash flow) to reveal the fluctuations in benefits which may occur throughout the project life. (These graphs are particularly useful in computing the Internal Rate of Return, IRR, page 200.)

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*Taxes are not a net benefit to the economy as a whole, only a transfer of resources within the society.

FIGURE 3

Computing the Net Incremental Benefit or Cash Flow Resulting from a Project

	Gross Costs	Gross Benefits	Net
With Project	C	B	$B - C$
Without Project	C'	B'	$B' - C'$
Increment Δ	$C - C' = \Delta C$ Incremental Cost CASH OUTFLOW	$B - B' = \Delta B$ Incremental Benefit CASH INFLOW	$\Delta B - \Delta C$ Net Incremental Benefit CASH OUTFLOW

EXAMPLE

A small farmer in Temasek (average holding of seven acres) has an average annual production cost of Ʉ100 (Ʉ = Unis, the Temasek currency note).* These costs include land preparation, cultivation, seed, and other production inputs. The current annual benefits were Ʉ160, giving the farmer a net profit of Ʉ60 per year.

The Ministry of Agriculture wanted to introduce small walking tractors (five to ten horsepower). A technical analysis of power requirements indicated that such a tractor would enable the farmer to cultivate more intensively (e.g., double cropping) and to expand his holdings, increasing his production by 200% (see Balis, 1974). This would eventually lead to a Ʉ360 rise in annual benefits with corresponding production costs of Ʉ130.** Tractor costs were initially a Ʉ500 investment with Ʉ50 for operation and maintenance per year. The estimated life was ten years with no salvage value.

The Ministry of Agriculture field staff prepared a financial cash flow analysis from the viewpoint of a typical farmer (see figure 2). By accounting convention, all costs and receipts were assumed to be paid at the end of each year. For example, the purchase price of the tractor was listed as an expense for the first year.

A diagram of the annual cash flows was constructed to clarify the components of the net incremental benefits. The analyst noted that, in the first year, the farmer would have a negative cash flow of Ʉ380. Therefore, many farmers needed financial assistance to purchase the tractor. Feasible loan arrangements were included in subsequent cash flows analyses. The interest costs of borrowing money were entered in the gross "with project" costs.

The net incremental benefits were estimated at Ʉ700 over the ten-year tractor life. Since the farmer would make Ʉ700 more than he would otherwise, the project seemed to be justified.*

The economic analysis of the farmer's tractor purchase option would look at the target group as a whole and the impact of the tractor purchases on the economy as a whole. This analysis involves many assumptions about the effective shadow prices for necessary farm inputs (e.g., fuel for the tractors and spare parts), the cost of labor, and effects on foreign exchange. This is beyond the scope of a non-economist. The reader is referred to the many texts on economic analysis (e.g., Gittinger, 1972).

THEORY

Cash flow analysis conceptualizes a stream of cash flowing out of a project or enterprise and an incoming stream. The cash outflow pays for capital goods, services, management, and labor for the project. The cash inflow is the benefit stream or returns to the project. The net cash flow, the difference between cash inflow and outflow, describes the dynamic transactions of the project at yearly intervals.

The description of cash flow analysis is drawn largely from Gittinger (1972) and the Economic Development Institute of the World Bank. The distinction between "with project" and "without project" situations is less critical than the difference between financial and economic analysis. If necessary, "without project" values can be incorporated into the determination of the benefits expected from the project (e.g., reduced labor costs brought about by a product can be treated as an incremental benefit of the project).

However, the difference between financial and economic analysis significantly affects the inputs to the cash

*In this example, the analysis is financial rather than economic, i.e., the cost estimates are all based on market values.

**It was assumed that the increase in seed, fertilizer, and other costs would be countered by a reduction in labor costs.

*This example is continued through a sequence of project analysis tools ending with Cost-Benefit Analysis.

flow analysis and the conclusions which may be drawn from the results. Adjustment of market prices by using shadow prices or some other multiplier is a complex process (see, for example, Bruce, 1976; Little and Mirlees, 1968; Squire and van der Tak, 1975; and Weckstein, 1971-72) and is the subject of some debate.

BIBLIOGRAPHY

Balis, John S. "The Utilization of Small Tractors in Integrated Agricultural Development: The Tractor Evaluation Project Applied." Cornell Agricultural Economics Staff Paper No. 74-15. Ithaca, N.Y.: Department of Agricultural Economics, Cornell University, June 1974.

Bruce, Colin. "Social Cost-Benefit Analysis: A Guide for Country and Project Economists to the Derivation and Application of Economic and Social Accounting Prices." World Bank Staff Working Paper No. 239. Washington, D.C.: International Bank for Reconstruction and Development, August 1976.

Gittinger, J.P. *Economic Analysis of Agricultural Projects.* Baltimore, Md.: Johns Hopkins University Press, 1972.

Little, I.M.D., and Mirlees, J.M. *Manual of Industrial Project Analysis in Developing Countries.* Vol. 2. Paris: OECD Development Center, 1968.

Sirken, Irving A. "Cost-Benefit Analysis: The Technique, Its Uses and Limitations." Paper prepared for the Economic Development Institute, World Bank, Washington, D.C., n.d.

Squire, Lyn, and van der Tak, Herman G. *Economic Analysis of Projects.* A World Bank Research Publication. Baltimore, Md.: Johns Hopkins University Press, 1975.

USDA. *Manual on Agricultural Projects Analysis.* Washington, D.C.: USDA, 1971, pp. FAL-67.

Weckstein, R. S. "Shadow Prices and Project Evaluation in Less-developed Countries." *Economic Development and Cultural Change* 20 (1971-72): 474-94.

Discounting

PREREQUISITE TOOLS

None.

USAGE

PURPOSE

Discounting provides a basis for analyzing and comparing future streams of costs and benefits by reducing them to their equivalent *present worth*.

USES

1) Future payments, either single, a uniform series (annuity), or an irregular series can be converted to their present worth by using *discount factors* computed from an appropriate *discount rate*.

2) The difference between payments made now and payments made in the future can be translated into a constant discount rate to measure the preference for present as opposed to future benefits.

3) Discounting permits inclusion of *time preference* in analyzing the net value of a single project, and in comparing two or more projects with dissimilar time-streams of costs and benefits.

KEY DEFINITIONS

1) *Present worth* is the value today of a future payment.

2) *Discount rate* is a percentage rate (usually annual) which equates the present and the future worth of a payment.

3) A *discount factor* is a fraction between zero and one which gives the present worth of one monetary unit spent or received.

4) *Time preference* is the general preference of individuals for present over future receipts and for future over present expenditures.

5) *Opportunity cost* is the cost of committing resources to a particular use as measured by the highest return that could have been obtained by committing the same resources to an alternative use.

SHORT DESCRIPTION

Discounting is a process of converting a single future payment or series of future payments to their equivalent present worth. The computation requires specifying a discount rate from which a discount factor may be determined.

Discounting future payments accounts for the time preference for present rather than future benefits. By discounting, payments that occur at various times throughout the life of a project can be made equivalent to present payments. A complex flow of payments can be converted to a single net figure, facilitating the valuation of one project or a comparison between projects in a way that reflects time preference and *opportunity cost*. It is the reverse of the compound interest process.

ADVANTAGES

1) Discounting provides a logical basis (time preference-opportunity cost) for comparing payments at various times. It facilitates the valuation of a single project or a comparison between projects.

2) Discounting puts more value on near-term than on distant payments. Since more distant forecasts are generally less reliable than short-term forecasts, discounting increases the degree of confidence that the analyst may have in his valuation.

LIMITATIONS

1) Establishing the discount rate is a theoretically complex and practically difficult chore. It may be based on the long-term market interest rates on relatively safe investments, e.g., government bonds are investment securities after taxes. Most analysts would argue that this is too low, and the discount rate should be estimated from the opportunity costs of capital (DeNeufville and Stafford, 1971). Gittinger (1972, page 90) reports that most countries use discount rates of 8% to 15% in their analysis, with 12% being used most often. In practice, a high rate is preferable to a low one.

2) The choice of a particular rate will influence the attractiveness of a project and may determine the ranking among alternative prospects. It is often desirable to repeat the analysis with varying discount rates, all of which are considered reasonable on some basis. If the results differ widely, the decision maker should be made aware of the significance of the choice of rate.

3) The appropriate discount rate, like other interest rates, might be expected to vary over time; yet discounting generally treats the rate as a constant parameter. It is, of course, possible to use varying discount rates for varying future periods if you have a basis for making such detailed forecasts.

REQUIRED RESOURCES

LEVEL OF EFFORT

Discounting can be time consuming, but it is not a difficult task. First, the appropriate discount rate must be determined. Then the discount factor is either computed or read from tables. Finally, the present worth is computed by multiplying the future payment by the discount factor. A pocket calculator and pretabulated discount factors reduce the effort.

SKILL LEVEL

Establishing the appropriate discount rate requires some expertise and subjective judgment. The opportunity cost of capital must be estimated, requiring a knowledge of the best return from alternative sources of investment.

The rest of the discounting process is rather mechanical and has a built-in self-checking process (see General Procedure).

TIME REQUIRED

The time required to discount a series of payments is a function of 1) the number of payments, 2) whether they are uniform or irregular, and 3) the availability of calculators and discount tables. This time is insignificant compared to the effort and time required to estimate the cash flow of future payments (see CFA, page 177).

SPECIAL REQUIREMENTS

A pocket calculator and a set of discount tables not only speed up the process, they help to eliminate simple errors in computation.

DESCRIPTION OF TOOL

SUPPLEMENTAL DEFINITIONS

1) DF [r/n] = discount factor of an amount paid at end of year n at r discount rate (%).

2) ADF [r/n] = annuity discount factor at r discount rate (%) for n years.

3) PW [r/n] = present worth at discount rate r (%) of amount paid during n years.

For example, PW [15%/10] = -500 DF [15%/1] + 120 ADF [15%/10] is the present worth (at a discount rate of 15%) of a single disbursement of 500 units at year 1 and receipts of an annuity of 120 units for 10 years.

REQUIRED INPUTS

Computing the present worth requires:

1) The specification of the appropriate discount rate (see, for example, Hinrichs, 1969).

2) A tabulation of the future payments (costs or benefits) for each year (see Cash Flow Analysis, CFA, page 177).

TOOL OUTPUT

Discounting gives the present worth of a future payment or stream of payments. This discounted value can be used to compute financial criteria for project evaluation:

1) the net present worth (NPW, page 188);
2) the benefit-cost ratio (BCR, page 194); and/or
3) the internal rate of return (IRR, page 200).

Any one of these measures may be used in the cost-benefit analysis of a single project or multiple projects.

IMPORTANT ASSUMPTIONS

Discounting reflects the preference for benefits now rather than at some later time. This time preference assumes that there is an opportunity cost in waiting to receive the benefits. One cost is the opportunity to invest in an alternative project which will yield a greater return than the amount invested. The second cost is the uncertainty of receiving delayed payments. The risk increases with the period of delay.

METHOD OF USE

GENERAL PROCEDURE AND EXAMPLES

Discounting a Single Future Payment

1. **Determine the discount rate, r (see Net Present Worth, NPW, page 188).**
2. **Compute the discount factor, DF $[r/n]$:**

$$DF[r/n] = 1/[1+(r/100)]^n \quad [1]$$

where

n = number of years hence that the payment will occur

r = discount rate (%)

Or, determine the discount factor from the appropriate discounting table (see Gittinger, 1973).*

3. **Multiply the discount factor by the payment amount to get the present worth:**

$$PW = \text{Payment} \times DF[r/n] \quad [2]$$

The present worth of a \$200 payment five years hence was computed for discount rates of 10%, 15%, and 20%.

At a discount rate of 10%, the discount factor is:

$$DF[10\%/5] = 1/[1+(10/100)]^5 = 0.621.$$

The present worth is:

$$PW = (\$200 \times 0.621) = \$124.$$

The other discount factors are:

$$DF[15\%/5] = 0.497$$
$$DF[20\%/5] = 0.402,$$

giving present worths of \$99 and \$80, respectively.

*Discount factors for a single payment are always less than one. Usually, three significant figures are sufficient accuracy.

FIGURE 1
Computing the Present Worth of a Series of Nonuniform Payments

Year	Payment (or receipt)*	Discount Factor at 20%	Present Worth
1	(100)	0.833	(83)
2	(100)	0.694	(69)
3	200	0.579	116
TOTAL	0	2.106	(36)

*Negative amounts are shown in the table in parentheses.

Discounting a Series of Nonuniform Payments

1. **Determine the discount rate, r.**
2. **Construct a table which lists the year and the payment amount in each year (see figure 1).**
3. **Determine the discount factor for each year at the appropriate discount rate.**
4. **Determine the present worth of each yearly payment.**
5. **Compute the sum of the present worths in order to give a single value. (Payments may be both negative expenditures and positive receipts.)**

Two \$100 expenditures were to be made in consecutive years in order to receive \$300 at the end of the third year. The present worth of the three payments was computed by determining the present worth of each payment and summing (see figure 1). Two conventions were used: 1) all payments are assumed to occur at the end of the year (which means that the first expenditure must also be discounted); 2) expenditures are negative amounts (shown in parentheses) and receipts are positive. If the three payments are summed, the investor gains \$100. However, using a discount rate of 20%, the sum of the discounted payments is only \$22. A higher discount rate would further reduce the present value of the series of payments.

Discounting an Annuity

1. **Determine the discount rate, r.**
2. **Compute the annuity discount factor, ADF $[r/n]$:**

$$ADF[r/n] = \sum_{i=1}^{n} 1/[1+(r/100)]^i \quad [3]$$

where

$\sum_{i=1}^{n}$ = the sum of terms of index i, i ranging from 1 to n.

n = the number of years for which the annuity is to be paid, each payment falling at the end of the year

r = discount rate (%)

The annuity discount factor may be computed from the single payment discount factor:

$$ADF[r/n] = \frac{1-DF[r/n]}{r/100} \qquad [4]$$

Or, the annuity discount factor* may be determined from discounting tables.

3. Multiply the annuity discount factor by the uniform payment amount to get the present worth of the series of future payments.

$$PW\ (series) = payment \times ADF\ [r/n] \qquad [5]$$

A series of five-year-end payments of $40 each were discounted to determine their present worth at a discount rate of 15%.

The annuity discount factor was computed:

$$ADF[15\%/5] = \frac{1-DF[15\%/5]}{15/100} = \frac{1-0.497}{0.15} = 3.352$$

The present worth is:

$$PW = (\$40 \times 3.352) = \$134.$$

Discounting a Uniform Series of n Payments Which Have Been Delayed d Years

1. Determine the discount rate, r.
2. Determine the annuity factors:

$$ADF\ [r/d]$$
$$ADF\ [r/(n+d)]$$

where

n = number of yearly payments
d = years before first payment is made
$(n+d)$ = year in which final payment will occur

3. Subtract the present worth of the payments made during the delay from the present worth of the payments as computed from the present to the final payment in year $n+d$.

$$PW = payment \times ADF[r/(n+d)] - payment \times ADF[r/d] \qquad [6]$$

A project which has a life of 15 years required an initial investment of $500 during the first year. The project will yield $1,000 in ten equal payments beginning six years later. If the discount rate is 12%, the present worth of the investment is:

$$\begin{aligned} PW &= \$500 \times DF[12\%/1] \\ &+ \$100 \times ADF[12\%/(5+10)] \\ &- \$100 \times ADF[12\%/5] \\ &= (\$500 \times .893) + (\$100 \times 6.811) \\ &- (\$100 \times 3.605) \\ &= \$446 + \$681 - \$360 \\ &= \$767 \end{aligned}$$

*The factor is often called the series discount factor or the uniform series discount factor.

Note: Although present worths of future payments can be summed algebraically, the discount factors alone may not, e.g., $ADF[r/(n+d)] - ADF[r/d] \neq ADF[r/n]$.

THEORY

Discounting is the reciprocal process to compounding an amount at a fixed interest rate. The discount rate corresponds to the interest rate mathematically. However discounting is used for analyzing projects, the discount rate does not correspond to the interest rat~ on investments savings. Interest on savings may be much lower than the return rate from a project. The discount rate is selected to correspond to the highest return available from alternative investments. This represents the time value of money (World Bank, 1975) as an opportunity cost. The cost of investments not made (the loss of a higher rate of return) figures prominently in the evaluation of projects using a discounted measure of project worth.

It is possible to evaluate cost and benefit streams at any point in the life of the project. Discounting can be used to determine the equivalent worth of payments after the analysis date, and compounding can be used to determine the equivalent worth of payments occurring before that date. The advantage of using discounting is that the greater weight is placed on cost and benefit estimates in the near future. In fact, the discount factors for discount rates greater than 15% and more than 20 years in the future are negligible. Consequently, these distant estimates (which tend to be increasingly uncertain) figure less in the evaluation of the project.

BIBLIOGRAPHY

DeNeufville, R. and Stafford, J. *Systems Analysis for Engineers and Managers.* New York: McGraw-Hill, 1971.

Gittinger, J. Price, ed. *Compounding and Discounting Tables for Project Evaluation.* EDI Teaching Materials Series No. 1. Washington, D.C.: International Bank for Reconstruction and Development, 1973. Distributed by The Johns Hopkins University Press, Baltimore, Md.

Gittinger, J. Price. *Economic Analysis of Agricultural Projects.* Baltimore, Md.: The Johns Hopkins University Press, 1972.

Hinrichs, Harley H., and Taylor, Braeme M. *Program Budgeting and Benefit-Cost Analysis.* Pacific Palisades, Calif.: Goodyear Publishing Co., 1969.

World Bank. *Cost-Benefit Analysis: The Time Value of Money.* Participant's Manual and Organizer's Guide. Washington, D.C.: International Bank for Reconstruction and Development, 1975.

Net Present Worth

PREREQUISITE TOOLS

Cash Flow Analysis (CFA, page 177) and Discounting (DIS, page 184).

USAGE

PURPOSE

Net present worth evaluates project net benefits by comparing different time streams of benefits and costs.

USES

Net present worth is used as:

1) A criterion for deciding if a single project should be funded.

2) A criterion for choosing among *mutually-exclusive* projects.

3) An intermediate calculation in determining a project's internal rate of return (IRR, page 200).

KEY DEFINITIONS

1) *Discounted cash flow* is a single value which represents the present worth of the net incremental benefits estimated for each project year. It is computed by discounting annual cash flows at a specified discount rate.

2) *Mutually-exclusive* projects are incompatible alternatives—implementing one precludes implementing the others. A project's alternative time phasings may also be analyzed in this manner.

3) *Rank-ordering* is the process of weighting one item against others and then ordering the items by weight on a scale such as importance or priority.

SHORT DESCRIPTION

Net present worth measures a project's financial and economic viability by taking into account a time preference for money. The difference between "with project" and "without project" benefits and the similarly derived incremental costs determine annual cash flows (see CFA, page 177). The net present worth is determined from the *discounted cash flow*. Alternatively, computing the difference of the project's discounted annual incremental benefits and discounted annual incremental costs gives the net present worth.

An appropriate discount rate must be selected in order to estimate the opportunity costs corresponding to delayed benefits and alternative investments. A positive net present worth indicates that the projected return from the project investment is greater than the estimated opportunity to invest elsewhere.

ADVANTAGES

Net present worth reduces benefits and costs occurring at different times to a comparable basis: the equivalent value today. This permits comparison between alternatives and provides a decision rule for funding a single project.

Net present worth estimates the amount that discounted benefits exceed discounted project costs.

LIMITATIONS

Investment decisions using net present worth as a criterion are often sensitive to the choice of a discount rate. Consider, for example, two projects having identical benefit streams and equivalent total costs. A high discount rate favors the project having lower initial investment but higher annual costs; annual costs are weighted less heavily in the computation of net present worth.

Net present worth gives the size of projected benefits from a project, but it gives no indication of how well the project uses the capital investment—the return on capital. Consequently, net present worth is not a valid measure for rank-ordering projects when funds are limited (Gittinger, 1972, page 92).

REQUIRED RESOURCES

LEVEL OF EFFORT

The major effort is in compiling the necessary cost and benefit data (see Cash Flow Analysis, CFA, page 177). The subsequent determination of net present worth is straightforward once the appropriate discount rate has been determined.

TIME REQUIRED

The first stages of identifying and estimating costs and benefits require the most time. The actual computation is easier with a simple hand calculator and appropriate discount tables (for example, Gittinger, 1973). See Discounting, DIS, page 184.

DESCRIPTION OF TOOL

REQUIRED INPUTS

Computation of the net present worth requires two primary inputs:

1) A description of the annual benefits and costs for the project (Cash Flow Analysis, CFA, page 177).

2) Information on the opportunity cost of capital in order to determine an appropriate discount rate (see Discounting, DIS, page 184).

TOOL OUTPUT

The technique gives a quantitative measure of the gain to be expected from a project measured in terms of its equivalent present worth. This criterion can then be used for funding decisions. Net present worth is also an intermediate calculation when determining a project's internal rate of return (IRR, page 200).

IMPORTANT ASSUMPTIONS

The net present worth criterion assumes that benefits and costs can be discounted at a discount rate which reflects the opportunity cost of tying up project resources for the life of the project.

METHOD OF USE

GENERAL PROCEDURE

1. Determine the incremental benefits and costs for each year of the project (see Cash Flow Analysis, CFA, page 177).

2. Specify the discount rate (see Discounting, DIS, page 184).

3. Determine the present worth of the incremental costs by discounting each annual cost at the discount rate.

4. Determine the present worth of the incremental benefits.

5. Compute the net present worth from the difference:

$$NPW = PW_b - PW_c$$

where PW_b is the present worth of incremental benefits and PW_c is the present worth of incremental costs.

6. Apply the criterion to the evaluation of the project:

a) If NPW is greater than zero, the project is accepted.

b) If NPW is less than zero, the project is not financially acceptable.

c) If NPW equals zero, the project's rate of return is equal to the discount rate (see Internal Rate of Return, IRR, page 200).

7. When comparing the net present worth for two or more mutually-exclusive projects, select the project with the greatest positive net present worth.

EXAMPLE

The annual cash flow for a small farmer tractor utilization project was computed in the Cash Flow Analysis technique (see figure 2, CFA, page 180).

FIGURE 1

Computing the Net Present Worth: Small Farmer Tractor Utilization–Purchase Option

Year	GROSS INCREMENTAL COSTS Investment	Other ₡	Gross	Discount factor at 15%	PRESENT WORTH OF GROSS INCREMENTAL COSTS ₡	GROSS INCREMENTAL BENEFITS ₡	PRESENT WORTH OF GROSS INCREMENTAL BENEFITS ₡	CASH FLOW ₡	PRESENT WORTH OF CASH FLOW ₡
1	500	80	580	0.870	505	200	174	(380)	(331)
2	0	80	80	0.756	60	200	151	120	91
3	0	80	80	0.658	53	200	132	120	79
4	0	80	80	0.572	46	200	114	120	68
5	0	80	80	0.497	40	200	99	120	59
6	0	80	80	0.432	35	200	86	120	51
7	0	80	80	0.376	30	200	75	120	45
8	0	80	80	0.327	26	200	65	120	39
9	0	80	80	0.284	23	200	57	120	34
10	0	80	80	0.247	20	200	49	120	29
Total	500	800	1300	5.019	838	2000	1002	700	164

Net Present Worth = Present Worth of Gross Incremental Benefits Minus Present Worth of Gross Incremental Costs

NPW = ₡1002 - ₡838 = ₡164

FIGURE 2
Cash Flow Analysis: Small Farmer Tractor Utilization–Rental Option

YEARS FROM START OF PROJECT

	1	2	3	4	5	6	7	8	9	10	TOTAL
WITHOUT PROJECT											
Gross Costs	Unis (₩) (Temasek National Currency)										
Usual Production Expenses	100	100	100	100	100	100	100	100	100	100	1000
Gross Benefits	160	160	160	160	160	160	160	160	160	160	1600
Net Benefits (Annual Profit)	60	60	60	60	60	60	60	60	60	60	600
WITH PROJECT											
Gross Costs											
Production Expenses											
Usual Expenses	120	120	120	120	120	120	120	120	120	120	1200
Tractor and operator rental fee	40	40	40	40	40	40	40	40	40	40	400
Gross Benefits	240	240	240	240	240	240	240	240	240	240	2400
Net Benefits (Annual profit)	80	80	80	80	80	80	80	80	80	80	800
CHANGES DUE TO PROJECT											
Incremental Costs (Cash outflow)	60	60	60	60	60	60	60	60	60	60	600
Incremental Benefits (Cash inflow)	80	80	80	80	80	80	80	80	80	80	800
Net Incremental Benefits (Project annual cash flow)	20	20	20	20	20	20	20	20	20	20	200

FIGURE 3

Net Present Worth Calculated from Discounted Cash Flow for Tractor Utilization—Rental Option

Year	Discount factor at 15%	GROSS INCREMENTAL COSTS ₡	GROSS INCREMENTAL BENEFITS ₡	NET INCREMENTAL BENEFITS (CASH FLOW) ₡	PRESENT WORTH OF CASH FLOW ₡
1	0.870	60	80	20	17.4
2	0.756	60	80	20	15.1
3	0.658	60	80	20	13.2
4	0.572	60	80	20	11.4
5	0.497	60	80	20	9.9
6	0.432	60	80	20	8.6
7	0.376	60	80	20	7.5
8	0.327	60	80	20	6.5
9	0.284	60	80	20	5.7
10	0.247	60	80	20	4.9
Total	5.019	600	800	200	100.2

Net Present Worth:

NPW = Sum of discounted annual cash flows for life of project = ₡100.2 = ₡100

Computing NPW using annuity discount factor (see DIS, page 184):

NPW = ₡20 ADF[15%/10] = (20)(5.019) = ₡100

The net present worth of the project was to be calculated using a discount rate of 15%, the assumed opportunity cost of capital. The calculations (see figure 1) gave a net present worth of ₡168. Since this measure was positive, the investment was financially sound.

Farmers in this region also had the option of renting a tractor. The tractor and operator rental fee were estimated at ₡40 for a ten-year period. A cash flow analysis indicated an annual cash flow of ₡20 (see figure 2). The net present worth for this option was also calculated at a 15% discount rate by directly discounting the net incremental benefits (see figure 3). The net present worth was projected to be ₡100 for this option.

Both options had a positive net present worth, but the farmer would gain more by purchasing the tractor since the discounted net benefit is greater.

THEORY

The analytical formula* for the net present worth is:

$$NPW = \sum_{i=1}^{n} (\Delta B_i - \Delta C_i) / [1 + (r/100)]^i$$

where

n = number of years of the project

ΔB_i = gross incremental benefits of the project for year i

ΔC_i = gross incremental costs of the project for year i

r = discount rate (%)

The formula may be modified to include varying discount rates and inflation factors (Fleischer, 1972). But

*See also figure 3, Cash Flow Analysis, CFA, page 182.

each element is an estimate which requires careful judgment by the analyst. The project life, n, must be estimated: the incremental benefits must be estimated and projected, often from sparse data of the "without" project situation. These estimates become more questionable as the project life increases. Finally, one must exercise caution in choosing the appropriate discount rate for the analysis.

Nevertheless, net present worth is a popular means for evaluating projects, partly because it corresponds to the commonly accepted notion of a time preference for money. Tradeoffs with other criteria are discussed further in Cost-Benefit Analysis (CBA, page 212).

BIBLIOGRAPHY

Fleischer, G. A. "Engineering Economic Analysis in Developing Countries. *Technos* (January-March 1972): 27-35.

Gittinger, J. Price, ed. *Compounding and Discounting Tables for Project Evaluation.* EDI Teaching Materials Series No. 1. Washington, D.C.: International Bank for Reconstruction and Development, 1973.

Gittinger, J. P. *Economic Analysis of Agricultural Projects.* Baltimore, Md.: The Johns Hopkins University Press, 1972.

Benefit-Cost Ratio

PREREQUISITE TOOLS

Cash Flow Analysis (CFA, page 177) and Discounting (DIS, page 184).

USAGE

PURPOSE

The ratio of project benefits to project costs evaluates the *efficiency* of project resource utilization.

USES

Benefit-cost ratio is a criterion for project evaluation which is used to:

1) Determine if a project should be funded.
2) Determine the *rank-ordering* of several projects.

KEY DEFINITIONS

1) *Rank-ordering* is the process of weighing one item against others and then ordering the items by weight on a scale such as importance or priority.

2) *Project efficiency* is the ratio of project outputs to inputs, e.g., the production rate for a given resource utilization rate.

SHORT DESCRIPTION

Benefit-cost ratios are computed by comparing the "with project" to the "without project" costs and benefits (see Cash Flow Analysis, CFA, page 177). The time preference-opportunity costs of money are weighed in the computation by discounting the benefit and cost streams (see Discounting, DIS, page 184). The benefit-cost ratio is the present worth of the gross incremental benefits divided by the present worth of the gross incremental costs.

A benefit-cost ratio greater than one means that the project benefits exceed the project costs when discounted at the opportunity cost of capital. The size of the benefit-cost ratio reflects the efficiency of the project. Rank-ordering projects according to the benefit-cost ratio gives the highest priority to the project which uses resources most efficiently.

ADVANTAGES

The benefit-cost ratio reduces the investment decision to a single number which reflects the proportion of total benefits to total costs. When total resources are limited, rank-ordering projects by the benefit-cost ratio maximizes the return for each investment dollar.

LIMITATIONS

The distribution of benefits and costs is not reflected in the benefit-cost ratio. One group in society may benefit at the cost of other groups (see Impact-Incidence Matrix, IPX, page 207).

Precisely because the benefit-cost ratio reduces the criterion to a single dimensionless number, the individual estimates, projections, and assumptions may be lost. Not all benefits can be quantified, nor expressed in monetary units. Hence, the benefit-cost ratio reflects only the economic aspects of efficient resource utilization.

If the projects are mutually exclusive, the benefit-cost ratio may give an erroneous ranking. A project may have a high benefit-cost ratio compared to other projects but a far smaller net present worth. Since the usual objective is to maximize the net benefit, the net present worth criterion is preferred for choosing between mutually-exclusive projects (see NPW, page 188).

REQUIRED RESOURCES

SKILL LEVEL

Judicious use of the benefit-cost ratio requires an understanding of the underlying assumptions used in the assessment. Projects can be erroneously justified by subjective selection of benefit and cost components, alternative valuations of the factors, and selective presentation of the results. The decision maker needs to recognize the relevance and accuracy of the analytic components.

TIME REQUIRED

The major time is spent gathering data. This may include surveying the project area to determine the "without project" situation and gathering baseline data to project the expected benefits of the project (see Surveys, SVY, page 36). The benefit-cost ratio computation for financial analysis is usually a straightforward calculation. An economic analysis requires more time as additional factors must be estimated (e.g., shadow prices for labor, foreign exchange, etc.).

SPECIAL REQUIREMENTS

A calculator and discounting tables simplify the computation procedure.

DESCRIPTION OF TOOL

REQUIRED INPUTS

The benefit-cost ratio requires accurate and reliable data on the relevant costs and benefits projected over the life of the project. These cash flows (see CFA, page 177) must be estimated and discounted according to an assumed discount rate. The latter requires information about the opportunity costs of capital.

TOOL OUTPUT

The ratio of benefits to costs provides a dimensionless criterion for financial evaluation of a project and for comparison of alternative projects. The benefit-cost ratio may be used to redesign project components to improve efficiency.

IMPORTANT ASSUMPTIONS

All benefits derived from the project are identifiable and measurable. The opportunity cost of capital is specified: if the benefit-cost ratio is less than one, the project is not returning as much as the best alternative investment (assuming one exists).

METHOD OF USE

GENERAL PROCEDURE

1. **Determine the incremental benefits and costs of the project for each year of the project life.**
   The incremental costs (benefits) reflect projected changes in costs (benefits) due to the project (see Cash Flow Analysis, CFA, page 177).

2. **Discount the annual incremental benefits and costs to determine their present worth.**
   An appropriate discount rate is selected in the discounting process (see DIS, page 184). This is usually the opportunity cost of capital.

3. **Compute the benefit-cost ratio.**
   $BCR = PW_b / PW_c$
   where PW_b is present worth of gross incremental benefits and PW_c is present worth of gross incremental costs.

4. **Apply the benefit-cost ratio as a criterion for project evaluation according to the following rules:**
   a) If the benefit-cost ratio is greater than or equal to 1.0, consider the project for funding.
   b) If the benefit-cost ratio is less than 1.0, then the project should not be funded.

6. **Apply the benefit-cost ratio as a criterion for selecting projects by rank-ordering the projects according to decreasing benefit-cost ratios.**

EXAMPLES

The projected cash flows of a project to purchase a small tractor were presented in figure 2 of Cash Flow Analysis (CFA, page 180). The benefit-cost ratio determined

FIGURE 1

Computing the Benefit-Cost Ratio for Small Farmer Tractor Utilization--Purchase Option

Year	GROSS INCREMENTAL COSTS Investment	Other	Gross	Discount factor at 15%	PRESENT WORTH OF GROSS INCREMENTAL COSTS ₡	GROSS INCREMENTAL BENEFITS ₡	PRESENT WORTH OF GROSS INCREMENTAL BENEFITS ₡
	₡						
1	500	80	580	0.870	505	200	174
2	0	80	80	0.756	60	200	151
3	0	80	80	0.658	53	200	132
4	0	80	80	0.572	46	200	114
5	0	80	80	0.497	40	200	99
6	0	80	80	0.432	35	200	86
7	0	80	80	0.376	30	200	75
8	0	80	80	0.327	26	200	65
9	0	80	80	0.284	23	200	57
10	0	80	80	0.247	20	200	49
Total	500	800	1300	5.019	838	2000	1002

BCR = Present Worth of Gross Incremental Benefits/Present Worth of Gross Incremental Costs = ₡1002/ ₡838 = 1.2

FIGURE 2

Cash Flow Analysis: Small Farmer Tractor Utilization – Tractor Cooperative Option

	YEARS FROM START OF PROJECT										
	1	2	3	4	5	6	7	8	9	10	TOTAL
WITHOUT PROJECT	Unis (Ɏ) (Temasek National Currency)										
Gross Costs											
Usual Production Expenses	100	100	100	100	100	100	100	100	100	100	1000
Gross Benefits	160	160	160	160	160	160	160	160	160	160	1600
Net Benefits (Annual Profit)	60	60	60	60	60	60	60	60	60	60	600
WITH PROJECT											
Gross Costs											
Usual Production Expenses	120	120	120	120	120	120	120	120	120	120	1200
Tractor Cooperative											
Annual membership fee (tractor maintenance and operating costs)	25	25	25	25	25	25	25	25	25	25	250
Initial Charter fee	150	0	0	0	0	0	0	0	0	0	150
Gross Benefits	270	270	270	270	270	270	270	270	270	270	2700
Net Benefits (Annual profit)	(25)	125	125	125	125	125	125	125	125	125	1100
CHANGES DUE TO PROJECT											
Incremental Costs (Cash outflow)	195	45	45	45	45	45	45	45	45	45	600
Incremental Benefits (Cash inflow)	110	110	110	110	110	110	110	110	110	110	1100
Net Incremental Benefits (Project annual cash flow)	(85)	65	65	65	65	65	65	65	65	65	500

FIGURE 3
Computing Benefit-Cost Ratios for Small Farmer Tractor Utilization—Cooperative Option

Year	GROSS INCREMENTAL COSTS Investment	Other ₡	Gross	Discount factor at 15%	PRESENT WORTH OF GROSS INCREMENTAL COSTS ₡	GROSS INCREMENTAL BENEFITS ₡	PRESENT WORTH OF GROSS INCREMENTAL BENEFITS ₡	CASH FLOW ₡	PRESENT WORTH OF CASH FLOW ₡
1	150	45	195	0.870	170	110	96	(85)	(74)
2	0	45	45	0.756	34	110	83	65	49
3	0	45	45	0.658	30	110	72	65	43
4	0	45	45	0.572	26	110	63	65	37
5	0	45	45	0.497	22	110	55	65	32
6	0	45	45	0.432	19	110	48	65	28
7	0	45	45	0.376	17	110	41	65	24
8	0	45	45	0.327	15	110	36	65	21
9	0	45	45	0.284	13	110	31	65	19
10	0	45	45	0.247	11	110	27	65	16
Total	150	450	600	5.019	357	1100	552	500	195

Net Present Worth = Sum of discounted cash flows = ₡195

BCR = Present Worth of Gross Incremental Benefits/Present Worth of Gross Incremental Costs = ₡552/₡357 = 1.54 = 1.5

from gross incremental benefits and costs discounted at 15% is 1.2 (see figure 1) This simply means that the decision to purchase the tractor is financially sound: the expected benefits will outweigh the expected costs for the life of the tractor.

The small farmer has another option: he may form a tractor cooperative. The cooperative would pool the members' resources (or credit) to purchase a larger tractor. Each farmer would pay only the initial charter fee and an annual membership fee. Because the tractor's time is to be shared, the projected gross benefits for each farmer would be less than if he had purchased his own (smaller) tractor.

A cash flow analysis for the individual cooperative member reveals an annual cash flow of Ʉ125 after an initial cash outflow of Ʉ25 at the end of the first year (see figure 2). The net present worth for the project is Ʉ196 at a discount rate of 15%. The benefit-cost ratio is 1.5 (see figure 3). This latter measure treats charter membership in the cooperative as an investment. A similar financial analysis could be conducted from the cooperative's point of view.

The benefit-cost ratio may be computed from an economic analysis of the tractor utilization options. This involves a more sophisticated assessment of costs and benefits (see CFA, page 177), including shadow prices for labor and other inputs, and the sales for increased production (see, for example, Gittinger, 1973).

These examples are continued in Internal Rate of Return (IRR, page 200). The comparison between projects using the benefit-cost ratio is discussed in Cost-Benefit Analysis (CBA, page 212).

THEORY

The analytical formula for the benefit-cost ratio is:

$$\frac{\sum_{i=1}^{n} (\Delta B_i) / [1 + (r/100)]^i}{\sum_{i=1}^{n} (\Delta C_i) / [1 + (r/100)]^i}$$

where

n = the number of years of the project
ΔB_i = the gross incremental benefits for year i
ΔC_i = the gross incremental costs for year i
r = discount rate (%)

Each parameter of the formula represents an estimate by the project analyst. The estimated costs and benefits grow more uncertain as the number of years from the present increases. However, the discounting process gives more weight to the early project benefits and costs. As with net present worth (NPW, page 188), care must be excercised in establishing the appropriate discount rate.

The relation of benefit-cost ratio to other project criteria is discussed further in Cost-Benefit Analysis (CBA, page 212).

BIBLIOGRAPHY

Gittinger, J. Price. *Economic Analysis of Agricultural Projects.* Baltimore, Md.: The Johns Hopkins University Press, 1973.

US Department of Agriculture. *Manual on Agricultural Projects Analysis.* Washington, D.C.: USDA, n.d.

Internal Rate of Return

PREREQUISITE TOOLS

Cash Flow Analysis (CFA, page 177), Discounting (DIS, page 184), and Net Present Worth (NPW, page 188).

USAGE

PURPOSE

The internal rate of return (IRR) is a criterion for analyzing projects based on the percentage return on investment.

USES

1) The IRR is used as a criterion for evaluating the financial (and economic) advantages of a single project.

2) The IRR is used to rank projects according to the most efficient utilization of resources (see Cost-Benefit Analysis, CBA, page 212).

KEY DEFINITIONS

1) The *internal financial return* of a project is the rate of return derived from a financial analysis of the project cash flows, i.e., from the viewpoint of the individual, enterprise, or group.

2) The *internal economic return* of a project is the rate of return derived from an economic analysis of the benefits and costs to the society or economy of the country.

SHORT DESCRIPTION

IRR is one of three widely used criteria for evaluating the financial and economic viability of projects. Like net present worth (NPW, page 188), IRR is computed from the present worth of gross incremental benefits and costs. Unlike net present worth, IRR does not indicate the present worth of the net incremental benefit, i.e., the equivalent present amount of all future project benefits. Rather, the IRR is an efficiency measure, reflecting the payoff of the project in terms of the precent return on outlays. In this regard, it is similar to the benefit-cost ratio (BCR, page 194).

A project's IRR is the discount rate at which the present worth of the net incremental benefits is exactly zero. Since this cannot be solved analytically, it must be determined by interpolation.

The IRR is compared to opportunity costs to determine if the amount of return on investment is sufficiently high to justify the project. The difference between internal financial return and internal economic return is not only in the assessment of costs and benefits, but in deciding whether the return is sufficient for the individual or for the society, respectively.

ADVANTAGES

The IRR may be computed without specifying the discount rate which corresponds to the opportunity cost of capital. Net present worth and benefit-cost ratio require this specification.

The IRR is the preferred criterion for ranking projects when total funds are limited (Gittinger, 1972).

LIMITATIONS

The IRR cannot be determined if the annual cash flows for a project are always positive (or zero). There must be at least one negative yearly cash flow so that the discounted benefits are equal to the discounted costs.

The computation of the IRR may yield more than one discount rate which gives a zero net present worth. This usually occurs if there are large negative cash flows late in the project. However, most development projects start with an initially negative cash flow followed by a rising stream of benefits from which a single IRR may be computed.

REQUIRED RESOURCES

LEVEL OF EFFORT

Determining the IRR is more difficult than computing net present worth or benefit-cost ratio. There is no analytical solution for the IRR (except for uniform cash flows), and a trial and error process must be followed. The bulk of the effort is in assembling the necessary data for analysis (see Impact-Incidence Matrix, IPX, page 207).

SKILL LEVEL

Since computing the IRR is not a straightforward process, the analyst must be skilled, particularly in interpreting cash flow patterns (see Cash Flow Analysis, CFA, page 177).

TIME REQUIRED

Computing the IRR may take significantly longer than computing net present worth or benefit-cost ratio, but the overall process is primarily constrained by the availability of the appropriate data on cash flows.

DESCRIPTION OF TOOL

REQUIRED INPUTS

A complete analysis of the costs and benefits over the life of the project is required (see Cash Flow Analysis, CFA, page 177).

A criterion level for selecting or rejecting the project must be specified, preferably in advance. This level may be the opportunity cost of capital or the minimum rate of return which a funding agency will accept on the project.

TOOL OUTPUT

The technique gives a single measure, the percent of return on investment, which may be used as a criterion for funding or for ranking projects for funding. The IRR is compared to the specific criterion level, e.g., 15% minimum rate of return. If the IRR is larger, the project is recommended for funding. When ranking projects, those with the largest IRR should be funded first.

IMPORTANT ASSUMPTIONS

IRR assumes that one discount rate will apply during the life of the project. This is not necessarily a limiting assumption, but it does make the measure less flexible than net present worth (see Fleisher, 1972).

METHOD OF USE

GENERAL PROCEDURE

Computing the IRR for a project is basically a trial and error process which starts with a trial discount rate and uses the procedure for computing the net present worth. New discount rates are selected until one gives a zero net present worth.

1. **Determine the incremental benefits and costs for the life of the project.**
   This is essentially the procedure found in Cash Flow Analysis (see CFA, page 177). The net benefit for each year of the project is determined from estimates of "with" and "without" project benefits and costs.

2. **Estimate the discount rate for the first trial computation.**
   Select the discount rate by examining the cash flow pattern rather than by using the opportunity cost of capital. If the project involves large negative cash flows followed by a delay in benefits, then the IRR is relatively low (choose a trial discount rate in the 10% to 20% range). If the project has immediate positive cash flows (benefits are not delayed more than a year or two), then the IRR may be very high (choose a trial discount rate of 50% or more). If the cash flows for the project are never negative in any year of the project, then the IRR is infinite and cannot be used. Net present worth or benefit-cost ratio may be substituted.

3. **Compute the net present worth of the project for the trial discount rate.***
   Designate this value as NPW_1. If NPW is zero, then the

*r_1 = the trial discount rate.

FIGURE 1
Flowchart of Interpolation Procedure to Determine Internal Rate of Return

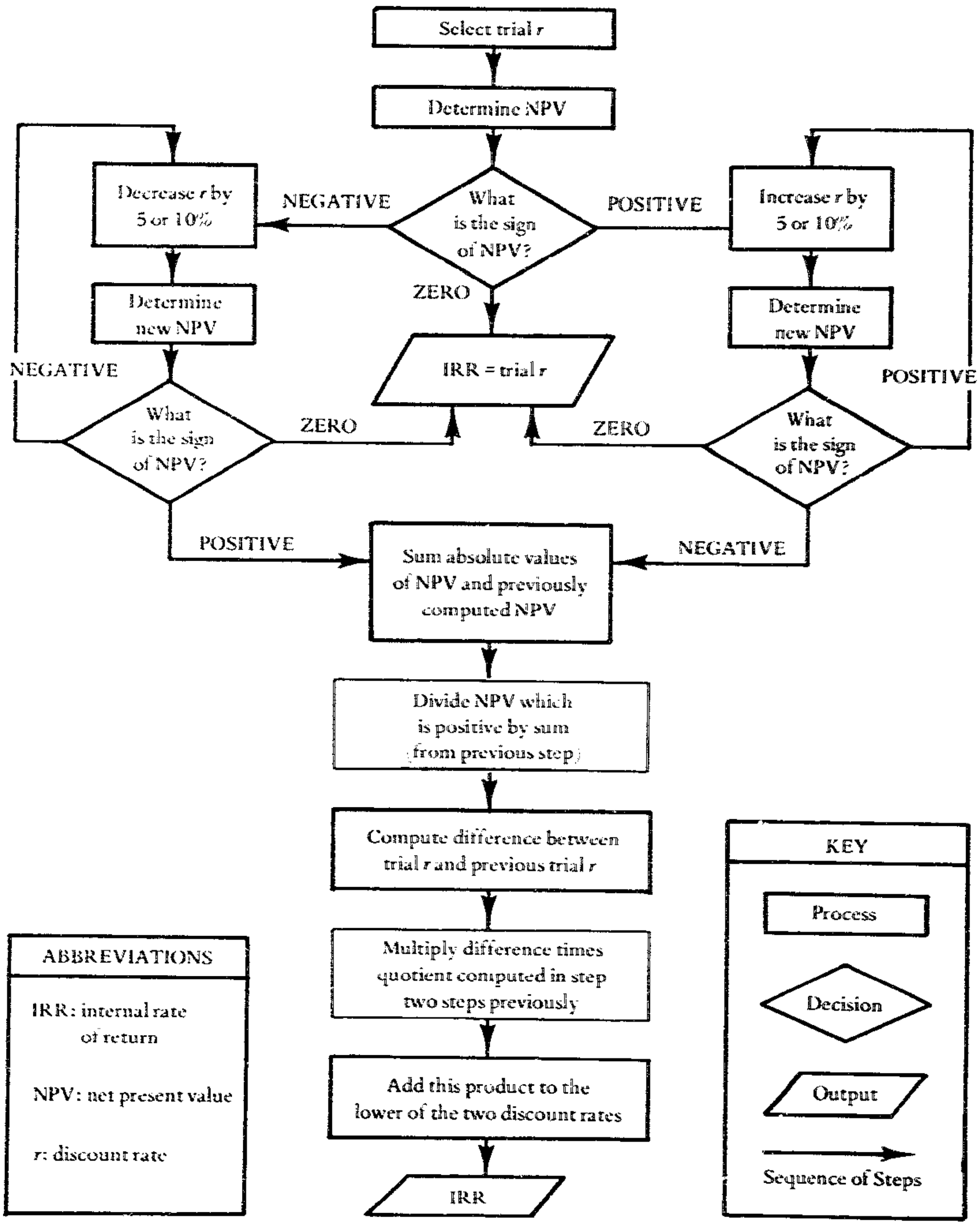

FIGURE 2
The Annual and Total Cash Flows for the Small Farmer Tractor Utilization Options

	OPTIONS		
	Purchase	Rental	Cooperative
Year	Net Incremental Benefits (Cash Flow)*	Net Incremental Benefits (Cash Flow)*	Net Incremental Benefits (Cash Flow)*
1	(380)	20	(85)
2	120	20	65
3	120	20	65
4	120	20	65
5	120	20	65
6	120	20	65
7	120	20	65
8	120	20	65
9	120	20	65
10	120	20	65
TOTAL CASH FLOW	700	200	500

*In Unis (Ʉ), Temasek National Currency

trial discount rate is the IRR. The first selected discount rate is unlikely to give a zero present worth, and the process must be repeated.

4. **Select a new trial discount rate, r_2.**
   If the NPW_1 is less than zero, select a discount rate smaller than r_1. How much smaller depends on how much NPW_1 is less than zero. Generally, select r_2 equal to 10% less than r_1. If NPW_1 is positive, then select a larger trial discount rate.

5. **Recompute the net present worth using the trial discount rate r_2.**
   Designate this discount rate as NPW_2.

6. **Select trial discount rates and compute net present worths until reaching both a positive and a negative present worth.**
   Increase the discount rate if the net present worth is still positive, and decrease the trial discount rate if the discount rate is negative.

7. **Estimate the IRR by interpolation:**

$$IRR = r_L + [\Delta r \times N_L / (|N_H| + |N_L|)] \quad [1]$$

where

r_L = lower discount rate
Δr = difference between discount rates
N_L = net present worth for lower discount rate
N_H = net present worth for higher discount rate

Note: The lower and higher discount rates must produce net present worths of opposite signs.

For example the lower discount rate (r_L) is 8% with a net present worth (N_L) of \$100. The higher discount rate is 10% with a net present worth (N_H) of - \$50. The sum of absolute values of the net present worths is \$150. Therefore,

$$\begin{aligned} IRR &= 8\% + [10\% - 8\% (\$100/\$150)] \\ &= 8\% + [2\% (.67)] \\ &= 8\% + 1.34\% \\ &= 9.34\% \end{aligned}$$

To reach a net present worth of zero, the IRR must be 9.34%.

This may be reduced to a simple procedure where the early years have a large negative cash flow and the later years have cash flows that are all positive. The flowchart in figure 1 may be used if the analyst is aware of the possibility that the multiple solutions to the IRR may exist (see Decision Tables, DTB, page 113).

FIGURE 3
Computation of the Internal Rate of Return for the Small Farmer Tractor Options

Algorithms for Net Present Worth

Purchase Option:
NPW[r%/10] = 120 ADF[r%/10] - 500 DF[r%/1]

Rental Option:
NPW[r%/10] = 20 ADF[r%/10]

Cooperative Option:
NPW[r%/10] = 65 ADF[r%/10] - 150 DF[r%/1]

Internal Rate of Return Computations:

Option 1: Tractor Purchase

r%	120	ADF[r%/10]	- 500	[DFR[r%/1]]	=	NPW[r%/10]
15		5.02		0.869		167.9
20		4.19		0.833		86.3
25		3.57		0.800		28.4
30		3.09		0.769		-13.7

INTERPOLATION: (see figure 2)

28.4 + 13.7 = 42.1
28.4/42.1 = 0.675
30 - 25 = 5
5 X 0.675 = 3.4
25 + 3.4 = 28.4 or 28% IRR

Option 2: Tractor Rental

IRR cannot be computed since the cash flow is always positive (see figure 2).

(Figure 3 Continued)

Option 3: Tractor Cooperative

r%	65 ADF[r%/10]	- 150 DF[r%/1]	= NPW[r%/10]
30	3.091	0.769	86.6
40	2.414	0.714	49.8
50	1.965	0.667	27.7
70	1.421	0.588	4.2
80	1.246	0.555	-2.3

INTERPOLATION: 4.2 + 2.3 = 6.5
4.2/6.5 = 0.646
80 - 70 = 10
10 X 0.646 = 6
70 + 6 = 76 or 76% IRR

EXAMPLE

Three options for small farmer tractor utilization have been presented in the prerequisite tools. The options and net annual cash flows are shown in figure 2. The benefit-cost ratio and net present worth for each option were calculated using a discount rate of 15% for the opportunity cost of capital.

The IRRs were calculated (figure 3); the procedure is given in the flowchart (figure 1). To simplify the repetitive calculation, an algorithm was developed (see Discounting, DIS, page 184).

If the farmer purchases the tractor, the estimated IRR is 28%. This is low for an agricultural project, but is well above the estimated rate of return from alternative investments, e.g., the 15% discount rate.

If the farmer joins a tractor cooperative, the IRR is 76%, which is more than double the IRR for purchasing. This indicates that joining the cooperative is the most efficient use of the farmers' limited resources.

The option of tractor rental has an infinite IRR. It cannot be calculated because the annual cash flow is always positive. This happens quite often in the financial analysis of agricultural projects where there is little or no capital investment.

Even though the IRR for the tractor cooperative is most efficient, further analysis is necessary before this alternative is recommended.

The computed IRRs represent the internal financial return of the project. In order to compute the internal economic return of the project, a similar procedure must be followed. However, the valuation of costs and benefits will be for the target group of farmers as a whole, and the prices will be adjusted (shadow-priced) to reflect more accurately the impact on the nation's economy. Because economic analysis is a more comprehensive and time-consuming process, and because many more assumptions are necessary, this task requires skills in macro-economics (see, for example, UNIDO, 1972).

THEORY

The internal rate of return is the discount rate r^* at which the net present worth is zero. It is given by solving the following equation for r^*:

$$\sum_{i=1}^{n} (\Delta B_i - \Delta C_i) / [1 + (r^*/100)]^i = 0 \qquad [2]$$

where

n = number of years of the project
ΔB_i = gross incremental benefits for year i
ΔC_i = gross incremental costs for year i
r^* = internal rate of return (%)

The formula cannot be solved analytically unless the pattern of benefits and costs are uniform. Otherwise, a trial and error approach (as described in the procedure) is necessary.

Considerable debate has addressed the practicality of the IRR as a criterion for project evaluation. Certain patterns of benefits and costs (in particular, a large cost near the end of a project) may result in more than one solution to equation [2]. Gittinger (1972) answers the critics by claiming that the multiple solution problem is not likely to occur for cash flows typical of development projects.

IRR is a widely used criterion for analyzing the financial and economic soundness of development projects. It has been adopted as the principal measure for project appraisal by the US Agency for International Development (USAID, Handbook 3). The distinction between internal financial return and internal economic return underlines the importance of both financial and economic analysis for project evaluation (Gittinger, 1972).

BIBLIOGRAPHY

Fleischer, G. A. "Engineering Economic Analysis in Developing Countries." *Technos* (January-March, 1972): 27-35.

Gittinger, J. Price, ed. *Compounding and Discounting Tables for Project Evaluation.* EDI Teaching Materials Series No. 1. Washington, D.C.: International Bank for Reconstruction and Development, 1972. Distributed by The Johns Hopkins University Press, Baltimore, Md.

Jones, William I. "Appraisal of an Agricultural Development Project: The Gambia." World Bank Case Study and Exercise Series, Report No. PA-142a. Washington, D.C.: International Bank for Reconstruction and Development. International Development Association, August 8, 1972.

UNIDO. *United Nations: Guidelines for Project Evaluation.* Vienna: UNIDO, 1972.

USAID. *Implementation of AID Assisted Projects.* Handbook 3, Part 2. Washington, D.C.: USAID.

Impact-Incidence Matrix

PREREQUISITE TOOLS

Benefit-Cost Ratio, BCR, page 194.

USAGE

PURPOSE

An impact-incidence matrix tabulates the distributions of project costs and benefits to the affected groups in the society.

USES

An impact-incidence matrix is used to:

1) Provide a decision maker with detailed information on the distribution of costs and benefits of a project or alternative projects.

2) Identify the relative gain or loss for various groups affected by the project.

3) Break down the benefit and cost data by type of measurement and accuracy.

4) Present measures of effectiveness and other non-monetary project impacts in conjunction with costs and income data.

5) Permit decision makers to examine the inequities in project design with regard to the distribution of benefits and costs.

SHORT DESCRIPTION

An impact-incidence matrix identifies the various groups affected either directly or indirectly by a project, and the cost and benefit measurements by type (see figure 1). The incidence of non-monetary project impacts is also tabulated, including strictly qualitative factors.

With the matrix, the decision maker has an expanded view of the attributes of the decision with regard to possible inequities in distribution. Benefit-cost ratios (BCR, page 194), are presented not only for the project as a whole, but for the affected groups (e.g., different income groups).

ADVANTAGES

1) In contrast to a single economic measure of project merit, the impact-incidence matrix requires the decision maker and the analyst to expand their assessment of a project to its distributional and qualitative impacts.

2) The disparities in impact-incidence among various groups are identified.

3) The type of measurement and the accuracy of the information is identified (e.g., an indirectly measured cost measurement is likely to be more subjective than a direct project cost estimate).

FIGURE 1
Impact-incidence Matrix for Cost Benefit Analysis

		Impact			
Groups impacted		*Directly estimated* $ a_1 a_2 a_3 ...	*Indirectly estimated* $ b_1 b_2 ...	*Estimated numerically not in* $ c_1 c_2 ...	*Estimated qualitatively in words* d_1 d_2 ...
Directly	A_1 A_2 . . .				
Indirectly	B_1 B_2 . . .				
Special interests	C_1 C_2 . . .				

NOTE: From *Systems Analysis for Engineers and Managers* by Richard DeNeufville and Joseph H. Stafford. Copyright (c) 1971 by McGraw-Hill Book Company. Used with permission of McGraw-Hill Book Company.

LIMITATIONS

1) Omitting either a group or an impact on a group is lessened by a systematic approach, but the danger still exists. The impact-incidence matrix may give a false sense of a comprehensive search for project impacts, when in fact the matrix is simply the tabulation of the results of that search. The information and analysis task must preceed the matrix tabulation.

2) It is one thing to identify a group affected by a project and another to ascertain the nature and extent of that effect. The skill of the analyst in searching out this information constrains the validity of the impact-incidence matrix as a decision-making tool.

REQUIRED RESOURCES

LEVEL OF EFFORT

Constructing an impact-incidence matrix and preparing summaries to pinpoint the findings is the tip of an iceberg. Lurking below is the difficult task of first identifying the impacts of the project and then identifying the groups that are affected. Where the groups are not immediately apparent, they may be categorized by distribution criteria (e.g., geographic, economic, ethnic). The relevant information can be gathered with a sample survey (SVY, page 36), which can be a major effort.

The information is rarely available from existing statistical data. The data are often so general that they are unreliable, and/or they are out-of-date. Nevertheless, the impact-incidence matrix is a useful format for designing and organizing information-gathering and analysis.

SKILL LEVEL

Cost data may require accounting, economics, and marketing to gather, assess, and interpret. Non-monetary factors require insight and an ability to grasp impacts of a project which are far-reaching and distant (both spatially and temporally). A variety of skills is essential. This suggests using a team approach, guided by systems concepts and forecasting tools (see Oval Diagramming, OVD, page 81).

TIME REQUIRED

The time required to construct an impact-incidence matrix is in direct proportion to the number of different groups affected by the project and the ways in which the project will affect them. An analyst completely familiar with the project environment and with ready access to data sources could construct a preliminary impact-incidence matrix in a week. This would then serve as a guide to estimate the time required for further information-gathering and analysis (anywhere from two to ten weeks).

IMPORTANT ASSUMPTIONS

The decision to go ahead with a project should not be made on simple economic criteria alone. Other measures are equally important if unintended or unexpected consequences are to be avoided (e.g., one group's failure to participate because of inequities).

Aggregated measures give only a general view of project merits. Disaggregating according to distributional criteria permits a decision maker to exercise judgment based on multiple attributes of the project impact.

DESCRIPTION OF TOOL

DEFINITIONS

1) A *multiplier effect* occurs when a project impact on one aspect of an economic system generates a stimulating effect on other aspects, e.g., when a labor generation project gives more money to consumers, which expands the economy, which leads to more jobs, etc.

2) *Direct market values* measure project costs or benefits which are assessed from equivalent market prices, e.g., average wages, construction costs, and price of inputs which are not subsidized.

REQUIRED INPUTS

Before the impact-incidence matrix can be constructed, the technical aspects of the project must be specified with enough detail to assess the likely impacts of the project on the social, economic, and environmental systems. For example, if a power plant is to be constructed and the likely alternates are a conventional fossil fuel burning plant or a nuclear powered plant, a separate impact-incidence matrix is required for each.

The objectives and purpose of the project must be clear in order to identify interest groups and affected organizations and individuals. Function Expansion (FEX, page 45), and intent structures (INS, page 55) are useful for this purpose.

TOOL OUTPUT

The technique results in an impact-incidence matrix which breaks down the elements of a cost-benefit analysis by the groups affected, the type of measurement, and the degree of accuracy. This permits the decision maker to examine the distributional effects of a proposed project as well as aggregated measures, such as the benefit-cost ratio (see BCR, page 194).

METHOD OF USE

GENERAL PROCEDURE

1. **Determine the groups affected by the project.**
   - 1.1 List all groups which are affected by or otherwise associated with the project.
   - 1.2 Categorize the groups by determining whether the project impact will be direct or indirect.
   - 1.3 Consider distributional criteria in categorizing the groups, e.g., geographic, economic, social or age status, occupational, property ownership.
   - 1.4 Identify any special interest groups who stand to gain or lose as a result of the project.
2. **Specify the costs and benefits accruing from the project.**
   - 2.1 Determine the directly estimable costs and benefits using criteria such as willingness to pay for the project product or service as well as *direct market values* for project costs or incomes accruing to each identified group.
   - 2.2 Determine indirectly estimable costs and benefits, such as cost savings and higher land projects as a result of project.
3. **Specify all other impacts of the project.**
   - 3.1 Determine those impacts—internal or external or tangible or intangible—which affect each group.
   - 3.2 As far as possible, quantify the impacts to give a numerical measure (see Multiple Criteria Utility Assessment, MCU, page 32).
4. **Compute the benefit-cost ratios (see BCR, page 194).**
   - 4.1 Add the directly and indirectly measured costs for each group; repeat for the benefits, and compute the benefit-cost ratio or benefits divided by the costs.
   - 4.2 Compute the total of all benefits and all costs across all groups and determine the benefit-cost ratio.

FIGURE 2
Impact-Incidence Matrix Example: Tractor Training Program

GROUP IMPACTED	IMPACTS: Directly Estimated	Indirectly Estimated	Estimated Numerically	Estimated Qualitatively
Directly:				
Small farmers (Number)	Reduced tractor maintenance and operating costs (+)	Increased production (+)	Reduced tractor down time (+)	Exposure to better farming practices (+)
University	Educational overhead costs per student*		Hours away from university classes (-)	Field exposure for staff & students (+)
Tractor manufacturers	Increased tractor sales (+) Reduced service revenues per tractor (-) Reduced training costs (+)	Increased implement sales (+)	Hours devoted to service and repair (-)	Goodwill of successful tractor operators (+)
Indirectly:				
Large farmers (Number)		Pool of trained personnel (+)		Increased level of mechanization** (+)
Fuel suppliers	Increased fuel sales (+)			
Farm input suppliers		Increased demand for production inputs (+)		Increased level of mechanization**
Landless laborers (Number)	Decreased farm labor demand (unskilled) (-)	Increased demand for produce handlers (+)	Reduced labor-days per hectare (-)	Migration to cities (-)
Special interest groups:				
Ministry of Agriculture extension service	Education overhead costs (-) Direct costs per student (-) Extension service overhead (-)		Increased contact hours with farmers (+)	Better acceptance of improved farming techniques (+)
Credit institutions		Loan service for increased purchases (+)		

NOTE: (+) positive benefit; (-) negative benefit or costs. These may be replaced by benefit-cost ratio where appropriate.

*Zero net cost for training each student because Ministry of Agriculture reimburses direct costs.

**Including more technicians, manufacturers, parts and maintenance services, implement choices, etc.

5. Prepare a summary of the data in the matrix.
   5.1 Identify those groups that would gain significantly or lose disproportionately as a result of the project.
   5.2 Discuss the significance of the individual and aggregated benefit-cost ratios.
   5.3 Clarify the assumptions about *multiplier effects* or other indirect consequences of the project.
   5.4 Relate non-monetary measures (and qualitative impacts to the affected groups and the project.

EXAMPLE

A project to assist farmers with the purchase of small tractors was started without giving full consideration to the farmers' difficulties in learning to use, operate, and maintain tractors. It was initially assumed that the tractor manufacturers would provide a brief training course; but when this was found to be inadequate, the manufacturers balked at providing a more extensive effort. The Ministry of Agriculture proposed to give this task to the Temasek University to be supervised by the Ministry's farm extension. All University costs were to be met with a donor agency loan, making the cost to the farmers nominal.

An impact-incidence matrix was prepared for the project to specify the costs vs. the benefits for the various groups which would be affected (see figure 2). Each entry in the matrix implied a set of assumptions about the training program and the impact of increased tractor utilization on the agricultural system.

A causal sequence of interaction was assumed:

Better utilization of tractors leads to greater acceptance of mechanization and increased production, which leads to more demand for production inputs and decreased demand for unskilled labor leading to higher unemployment for the landless except as balanced by higher volume of production, etc. This was the most likely scenario for the causal interactions in the system (see Oval Diagramming, OVD, page 81).

The analyst assigned values to the quantified impacts. A benefit-cost ratio was computed for the directly and indirectly estimated costs and benefits for each group. The quantifiable benefits outweighed the costs for all groups except the landless.

Consequently, the Ministry of Agriculture modified the training program to permit landless laborers to take part in the course, supported in part by a special tax on all tractor owners holding land in excess of 20 hectares.

THEORY

Cost-benefit analysis has produced an extensive literature which seeks either to rationalize or to discredit its use as a decision-making tool (see, for example, Layard, 1972).

Weighing the benefits against the costs of a course of action makes intuitive sense. However, there is little agreement on how or whether to attempt the task at all.

Maximizing the public welfare is no easy task; deciding what is in the public welfare is the first stumbling block. The impact-incidence matrix addresses the problem of the distribution of the benefits, costs, and other impacts of projects (Lichfield, 1966; Elliot and Picard, 1970). The impact-incidence breakdown is useful because of the juxtaposition of non-monetary measures of effectiveness with distributional projections of costs and benefits. The decision maker is presented with a disaggregation of benefits and costs according to the groups in society who stand to gain or lose by the project (DeNeufville and Stafford, 1971). While this counters a major criticism of cost-benefit analysis (de V. Graff, 1975) the problem still remains of identification and measurement of the incidence and impact of the project.

BIBLIOGRAPHY

DeNeufville, Richard N., and Stafford, J.H. *Systems Analysis for Engineers and Managers*. New York: McGraw-Hill, 1971, pp. 248-51.

de V. Graaf, J. "Cost-Benefit Analysis: A Critical View." *The South African Journal of Economics* 43 (1975).

Elliot, D., and Picard, D. *Use of Impact-Incidence Matrix: Airport Locations as an Example*. Research Report R70-34. Cambridge, Mass.: M.I.T. Department of Civil Engineering, June 1970.

Layard, Richard, ed. *Cost-Benefit Analysis: Selected Readings*. Middlesex, England: Penguin Books, 1972.

Lichfield, N. "Cost-Benefit Analysis in Urban Redevelopment: A Case Study." *Regional Science Association Papers* 16 (1966): 129-54.

Stewart, Frances. "A Note on Social Cost-Benefit Analysis and Class Conflict in LDC's." *World Development* 3 (January 1975): 31-39.

Cost-Benefit Analysis

PREREQUISITE TOOLS

Cash Flow Analysis, (CFA, page 177); Discounting, (DIS, page 184); Net Present Worth (NPW, page 188); Benefit-Cost Ratio (BCR, page 194); Internal Rate of Return (IRR, page 200); Impact-Incidence Matrix (IPX, page 207).

USAGE

PURPOSE

Cost-benefit analysis identifies, assesses, and weighs costs vs. benefits to evaluate the financial and economic merits of development projects.

USES

Cost-benefit analysis is used to:

1) Provide a comprehensive analysis of costs and benefits including secondary, indirect, intangible, and societal benefits and costs of a proposed project or program.

2) Provide measures for deciding whether a project is financially viable and, in the process of analysis, to raise questions for consideration in redesign or implementation.

3) Rank projects for funding priority.

4) Decide among alternative policies, strategies, or components of a single program, e.g., for Planning, Programming, and Budgeting (PPB, page 236).

SHORT DESCRIPTION

Cost-benefit analysis is a generic term covering a range of theoretical issues and practical techniques. Because cost-benefit analysis has practitioners in many disciplines, a universal approach has not evolved. This description presents the systems engineering approach which views cost-benefit analysis as a multi-stage process leading to a comprehensive picture of project benefits vs. costs (Bordman, 1973; DeNeufville and Stafford, 1971).

A systems approach using cost-benefit analysis begins by specifying objectives, generating technically feasible alternatives, and then evaluating their economic and social consequences. Techniques for determining evaluation criteria are listed as prerequisites. Cost-benefit analysis is a synthesis of these techniques as well as techniques for identifying objectives, generating alternatives, and gathering cost-benefit data.

Project costs are both direct (e.g., equipment, labor, management, physical resources) and indirect (e.g., displaced workers, pollution, added infrastructure requirements). Similarly, the benefits may be both direct (e.g., increased production, reduced transport costs, increased earning power, better health) and indirect (e.g., employment generation, support of local service enterprises, upgraded manpower). Some costs and benefits may be intangible (e.g., goodwill, improved morale, aesthetics), but are included in the presentation to decision makers (see Impact-Incidence Matrix, IPX, page 207).

Costs and benefits are identified and valued from three viewpoints:

1) The individual project entity (private or financial analysis).

2) The economic system (public or economic analysis, see Gittinger, 1972).

3) The socio-political-economic system (social cost-benefit analysis).

The second differs from the first in that market prices are adjusted to true equilibrium values using shadow prices or "accounting prices" (Little and Mirlees, 1974) (see Cash Flow Analysis, CFA, page 177). Social cost-benefit analysis is the more controversial approach of using "conversion factors" to weight cost-benefit estimates (Squire and van der Tak, 1975). Subjectively estimated factors incorporate social-political goals into the analysis, e.g., equitable distribution of project benefits favoring employment generation, or promoting independence from foreign goods.

ADVANTAGES

1) Cost-benefit analysis rationalizes the decision-making process to make the best allocation of scarce development resources. Attention is focused on the direct and indirect project impacts. Factors other than cost may enter into the computation and evaluation. Unintended side effects (indirect costs) and unequal distribution of benefits can often be pinpointed.

2) Socially desirable objectives may be explicitly treated as part of the evaluation criteria.

3) A common measurement dimension (monetary units) permits comparing alternatives.

LIMITATIONS

1) Many social costs and benefits cannot be quantified or accurately measured, e.g., the value of educational programs or the benefits of increased health, security, or aesthetics. Quantitative factors receive disproportionate emphasis simply because they are measurable. Cost-effectiveness analysis partly addresses this problem (see CEA, page 000).

2) Selecting projects using the benefit-cost ratio (BCR, page 194) or internal rate of return (IRR, page 200) presupposes that project efficiency is the overriding goal. Yet an efficient project may be ineffective; that is, it may contribute little to achieving development objectives (see Cost-Effectiveness Analysis, CEA, page 219).

3) If a project is of sufficiently large-scale, the increased production or other project outputs will have an impact on prices. Consequently, "no 'partial' measure of project worth is appropriate and much more elaborate analytical procedures must be called into play" (Gittinger, 1972, page 91).

4) Conversion factors for social-cost-benefit analysis are subjectively estimated value judgments. Conflict in values clouds the subsequent cost-benefit analysis (Stewart, 1975).

REQUIRED RESOURCES

LEVEL OF EFFORT

An overall analysis of the project is necessary in order to be aware of its social and economic effects, as well as its direct and indirect costs and benefits. An appropriate unit measure must be developed to evaluate each variable. However, value data are often not readily available. Sophisticated models may be necessary in order to calculate values for social variables (see Squire and van der Tak, 1975). The level of effort will vary with the number of project alternatives and variables being considered. In short, cost-benefit analysis is a difficult and demanding task.

SKILL LEVEL

Considerable skill and judgment are required to identify cost and benefit components, to estimate the changes over the life of the project, and to adjust the values using shadow prices or conversion factors. The latter is a particularly thorny task because of the difficulty, if not the impossibility, of getting the "right" shadow prices. Training in economic analysis and financial accounting is essential.

TIME REQUIRED

Cost-benefit analysis is a time-consuming exercise, particularly when cost and benefit data must be gathered by interview or survey (see SVY, page 36). Careful analysis and weighing of alternatives may take from several days to several weeks.

DESCRIPTION OF TOOL

REQUIRED INPUTS

A formal cost-benefit analysis begins after project goals have been defined and the alternative programs to meet those goals are specified (see Objectives Trees, OBT, page

49, and Morphological Analysis, MPA, page 10). In order to identify the social and economic components of both costs and benefits, a careful analysis of the project and its environment is essential (see Oval Diagramming, OVD, page 81). A systems viewpoint is recommended (see System Definition Matrix, SDM, page 67).

TOOL OUTPUT

A proper cost-benefit analysis presents recommendations to funding sources and decision makers, including:

1) The financial and economic merits of each project relative to minimum acceptable returns on the resources invested.

2) A rank-ordering of alternatives according to decreasing benefit-cost ratios or decreasing internal rates of return.

3) A concise statement of the assumptions inherent in the analysis and, where possible, the sensitivity of economic criteria to changes in assumptions and analytical parameters.

4) A discussion of intangible factors related to both economic and non-economic criteria.

IMPORTANT ASSUMPTIONS

All relevant project benefits and costs are identifiable before the project is implemented. Benefits and costs occurring at different times during the project may be valued at their present worths by assuming a discount rate. The discounting process reflects the time-preference for money, i.e., the opportunity costs associated with committing resources to the project and foregoing other investment alternatives (see Discounting, DIS, page 184).

It is usually assumed that inflation will affect all project alternatives equally and thus is ignored in projecting future cash flows. However, if inflation rates can be accurately estimated for each year of the project, the differential impact on both costs and benefits may be incorporated in the cash flow estimates.*

Weighing costs against projected benefits assumes that a net benefit accrues to society, i.e., that the project recipients may realize a net benefit which does not cause a negative benefit to some other segment of society (Sirken, n.d.). A comprehensive analysis of indirect costs and benefits theoretically reveals such anomalies, but this degree of thoroughness is not always feasible.

*G.A. Fleischer, "Engineering Economic Analysis in Developing Countries," *Technos* (January-March 1972): 27-35.

METHOD OF USE

GENERAL PROCEDURE

As there are numerous texts devoted exclusively to the subtleties of cost-benefit analysis, the following steps sketch the process in the broadest sense.

1. Identify the cost and benefit components expected to result from project implementation.

1.1 Identify those groups directly and indirectly affected by the project (see Impact-Incidence Matrix, IPX, page 207).

1.2 Identify and estimate all benefits and costs projected for the life of the project (see Cash Flow Analysis, CFA, page 177).

1.3 Summarize all assumptions of incremental costs and benefits in a clear format for examination by decision makers.

2. Determine the present worth of all future costs and benefits.

2.1 Discount the cash flows to the present using the appropriate discount rate (see Discounting, DIS, page 184).

2.2 Compute the net present worth of the project cash flow (see Net Present Worth, NPW, page 188).

3. Determine the efficiency measures of project performance.

3.1 Compute the benefit-cost ratio (see BCR, page 194).

3.2 Compute the internal rate of return (IRR, page 200).

4. Consider a project for funding if:

4.1 The net present worth is zero or positive where net present worth is computed at a discount rate equal to the opportunity cost of capital.

4.2 The benefit-cost ratio is 1.0 or greater (using benefits and costs which have been discounted at a rate equal to the opportunity cost of capital).

4.3 The internal rate of return is not less than a minimum acceptable rate of return, i.e., the opportunity cost of capital (usually specified at 15% or higher).

5. Rank alternative projects or components of a project.

5.1 Rank the alternatives in order of descending internal rate of return or benefit-cost ratio measures, unless the alternatives are mutually exclusive.

5.2 If the alternatives are mutually exclusive, select the one with the largest net present worth.

6. **Repeat steps 2 through 4 for each group directly affected by the project (see Impact-Incidence Matrix, IPX, page 207).**

7. **Contrast the financial analysis of the project with the economic analysis by separately computing costs and benefits from the viewpoint of the national economy.***
   7.1 Determine the costs and benefits for all directly and indirectly affected groups.
   7.2 Estimate the shadow prices for the factors of production.
   7.3 Estimate shadow prices for foreign exchange.
   7.4 Estimate shadow prices for government price supported commodities.
   7.5 Determine conversion factors for societal goals (optional), e.g., weighting benefits by income groups, favoring employment generating projects, promoting independence from foreign goods (see UNIDO, 1972, and Squire and van der Tak, 1975).
   7.6 Compute the criteria net present worth, benefit-cost ration, and internal rate of return using the adjusted cash flows.

8. **Complete the analysis with a consideration of nonmonetary impacts of the project.**
   8.1 Impacts which may be quantified (but not in monetary units) should be listed (see Impact-Incidence Matrix, IPX, page 207).
   8.2 Impacts which may be qualitatively estimated should be presented alongside the quantitative data. The relevant impact, importance, or significance of the factors may be assessed to aid decision makers (see Rating Scales, RTS, page 29, and Interaction Matrix Diagramming, IMD, page 92).

EXAMPLE

The Ministry of Agriculture in the country of Temasek commissioned a cost-benefit analysis of the utilization of small tractors by farmers having limited land-holdings (less than 15 hectares).** The project analysts identified the target group and considered three alternative means by which each farmer could acquire a tractor. These alternatives were:

Option 1: Purchase a five horsepower walking tractor.

Option 2: Rent a tractor and services of an operator.

Option 3: Form a cooperative to share in the purchase and maintenance of a 15 horsepower tractor.*

Financial analysis of the options began by estimating the projected cash flows: option (1) was analyzed in Cash Flow Analysis (CFA, page 177); option (2) was analyzed in Net Present Worth (NPW, page 188); and option (3) was analyzed in Benefit-Cost Ratio (BCR, page 194). The cash flows for the three options were summarized in Internal Rate of Return (IRR, page 200). A summary of assumptions which were necessary to contrast the "with" and "without" situations was prepared (see figure 1).

Four measures of financial soundness were computed (see figure 2). Option (1) gives the largest total cash flow over the ten-year life of the project. Option (3) gives the next largest cash flow. Alternative projects compared using the total cash flow criterion must have the same project life, ten years in this case. However, the time value of money is not considered in cash flow comparisons (see Discounting, DIS, page 184).

Discounted measures, net present worth, benefit-cost ratio, and internal rate of return take into account the line streams of benefits and costs. A discount rate of 15% was selected to reflect the best return of money invested in alternative projects.

The net present worth criterion applied to the three options indicates that all are financially feasible. Since the options are mutually exclusive (e.g., the farmer is not likely to rent and purchase a tractor simultaneously), the net present worth may be used to select the best project. Option (3) has the highest net present worth followed by option (1) (see figure 2). This simply means that if the farmer joins a tractor cooperative, the value of his future earnings translated to the present is more than for the other options.

Benefit-cost ratio and internal rate of return measure project efficiency. Ranking the options on the basis of benefit-cost ratio indicates that option (3) gives more benefits per unit of cost than option (2), and option (1) has the lowest ratio (see figure 2). The benefit-cost ratio rankings may differ from the net present worth rankings when there are differences in the relationships between gross benefits and operating costs for the two projects (see Gittinger, 1972, page 65).

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*These steps represent theoretically complex tasks which cannot be covered in a short description. The reader is referred to the project evaluation literature. See, for example, Gittinger, 1972; Little and Mirlees, 1974; Squire and van der Tak, 1975; Hinrichs, 1969; or UNIDO, 1972.

**This example was stimulated by the report by John Balis, "The Utilization of Small Tractors in Integrated Agricultural Development: The Tractor Evaluation Project Applied." Cornell Agricultural Economics Staff Paper No. 74-15 (Ithaca, N.Y.: Department of Agricultural Economics, Cornell University, June 1974).

*A fourth alternative is to continue current practices which utilize animal power. However, this alternative was treated in the cash flow analysis by determining the incremental costs and benefits—the difference between the "with project" and the "without project" costs and benefits.

FIGURE 1
Summary of Assumptions for Small Farmer Tractor Utilization

Projected Increases in Cost and Benefit Data and Percent Change (%Δ)							
	WITHOUT PROJECT	WITH PROJECT[1]					
		Option 1 Purchase		Option 2 Rent		Option 3 Cooperative	
Production Expenses[2]	₡	₡	%Δ	₡	%Δ	₡	%Δ
Usual expenses[3]	100	130	30%	120	20%	120	20%
Operation & maintenance	0	50		40		25	
Investment		500		0		150[4]	
Gross Benefits[5]	160	360	125%	240	50%	270	70%

[1] All costs and benefits are constant over the 10-year project life.
[2] Inflation affects all project costs equally.
[3] Additional costs of seeds and other inputs are compensated by reduced labor costs.
[4] The charter fee for joining the cooperative is an investment in shared ownership of the tractor.
[5] The increased production is realized in the first year of the project.

FIGURE 2
Comparing the Small Farmer Tractor Utilization Options

		Total Cash Flow	NPV ₡	BCR_{all}	BCR_{inv}	IRR %
Option 1 Purchase		700	168	1.2	1.4	28
Option 2 Rent		200	100	1.3	–	∞
Option 3 Cooperative		500	195	1.5	2.5	76
Rank Order of Options*	1st	1	3	3	2	2
	2nd	3	1	2	–	3
	3rd	2	2	1	1	1

*According to criterion.

Computing internal rate of return was not possible for all options* (see Internal Rate of Return, IRR, page 200). The internal rate of return for tractor rental was indeterminate. The third option has a significantly higher internal rate of return than option (1), and on this basis the farmer should join the cooperative rather than purchase his own tractor. However, since the projects were mutually exclusive, the internal rate of return would not normally be used for ranking, since it may give an erroneous ordering (see Gittinger, 1972).

An internal rate of return of 28% for option (1) simply means that this investment would generate a return on capital which would be equivalent to a compound interest rate of 28% per annum. While this was nearly double the estimated opportunity cost of capital, 15%, it was not particularly high for an agricultural project. The internal rate of return for option (3) is more representative of the returns to be expected.

Computing the criteria illustrates the mechanics of cost-benefit analysis. In order to develop a single metric for judging the financial worthiness of projects, many assumptions tend to get further submerged in the manipulations of the data.

The impact-incidence matrix presents not a single measure such as net present worth, but rather a tabulation of individual metrics computed for various groups directly or indirectly affected by the project (see Impact-Incidence Matrix, IPX, page 207). Who benefits and who loses if the small farmer mechanizes those tasks which require human or animal labor? Are all the benefits and costs quantifiable, let alone measurable, in monetary units? Answering these questions adds essential dimensions to cost-benefit analysis as a decision-making tool.

Many examples of cost-benefit analysis may be found in the literature, although only in the past decade has its application in service fields such as family planning, education, and health been documented.

The Gambia case study (Jones, 1972) presents an excellent treatment of the technical side of cost-benefit analysis applied to rice production. Frianeza (1974) has a fairly complete example of cost-benefit analysis applied to the local grape industry in the Phillipines. Bruce (1976) presents a case study of the application of conversion factors to social cost-benefit analysis along with a critique of the approach.

*The IRR may only be calculated if the incremental costs exceed the incremental benefits at least once in the life of the project. Since by convention all costs are computed at year-end, option (2) never has a negative cash flow.

THEORY

Cost-benefit analysis arose in the 1930s as a tool for evaluating water resource projects in the United States. Its application to other fields grew, producing a stream of critical comment (see, for example, Graaff, 1975; DeNeufville and Stafford, 1971; and Hines, 1962) and alternative approaches (Little and Mirlees, 1974, and UNIDO, 1972). The weakness of the cost-benefit approach and its contribution to decision making have been explored (see, for example, Hinrichs, 1969; Kendall, 1971; and Layard, 1972).

The work of Gittinger (1972) and the Economic Development Institute of the World Bank in developing a comprehensive approach to the analysis of agricultural projects provided the basis for the techniques in this set of tools. The problems of applying cost-benefit analysis to other sectors have been reported (see Sirken, n.d., and Divine, 1966), though much remains to be learned about valuing the benefits and the costs of social service programs.

Social cost-benefit analysis, which attempts to weight cost-benefit factors to incorporate societal goals, is a complex process (Squire and van der Tak, 1975). There are many problems with the added complexity and the possibility that value judgments are hidden from decision makers. Many argue that the best analysis presents a broad array of evaluation criteria to the decision maker, rather than attempting to produce a highly aggregated single figure of project merit (Bruce, 1976, and Stewart, 1975).

BIBLIOGRAPHY

Bordman, Sanford. "Improving the Accuracy of Benefit-Cost Analysis." *IEEE Spectrum* (September 1973).

Bruce, Colin. "Social Cost-Benefit Analysis: A Guide for Country and Project Economists to the Derivation and Application of Economic and Social Accounting Prices." World Bank Staff Working Paper No. 239. Washington, D.C.: International Bank for Reconstruction and Development, August 1976.

Burns, Leland S. "Cost-Benefit Analysis of a Housing Project." *Development Digest* (USAID) 4 (April 1966): 53-57.

DeNeufville, R., and Stafford, J.H. *Systems Analysis for Engineers and Managers*. New York: McGraw-Hill, 1971.

de V. Graaff, J. "Cost-Benefit Analysis: A Critical View." *The South African Journal of Economics* 43 (1975).

Divine, E.J. "The Treatment of Incommensurables in Cost-Benefit Analysis." *Land Economics* (August 1966).

Frianeza, Leonardo I. "Prospects of the Local Grape Industry: A Benefit-Cost Approach Analysis." *NEDA Journal of Development* 1 (First Semester 1974): 142-57.

Gittinger, J.P. *Economic Analysis of Agricultural Projects.* Baltimore, Md.: The Johns Hopkins University Press, 1972.

Haveman, Robert. *The Economics of the Public Sector.* New York: John Wiley and Sons. 1973.

Hines, Lawrence. "The Hazards of Benefit-Cost Analysis as a Guide to Public Investment Policy." *Public Finance* (1962).

Hinrichs, Harley H. "Government Decision Making and the Theory of Benefit-Cost Analysis: A Primer." In *Program Budgeting and Benefit-Cost Analysis,* edited by Harley H. Hinrichs and Graeme M. Taylor. Pacific Palisades, Calif.: Goodyear Publishing Co., 1969.

Jones, William I. "Appraisal of an Agricultural Development Project: The Gambia." World Bank Case Study and Exercise Series. Report No. PA-142a. Washington, D.C.: International Bank for Reconstruction and Development, International Development Association, August 8, 1972.

Kendall, M.G., ed. *Cost-Benefit Analysis.* New York: American Elsevier, 1971.

Layard, Richard, ed. *Cost-Benefit Analysis: Selected Readings.* Middlesex, England: Penguin Books, 1972.

Little, I.M.D., and Mirlees, J.A. *Project Appraisal and Planning for Developing Countries.* London: Heinemann Educational Books, 1974.

Sirken, Irving A. "Cost-Benefit Analysis: The Technique, Its Uses and Limitations." Paper prepared for the [illegible]nomic Development Institute, World Bank, W[illegible]ton, D.C., n.d.

Squire, Lyn, and van der Tak, Herman G. *Econom[illegible]ysis of Projects.* A World Bank Research Publi[illegible] Baltimore, Md.: The Johns Hopkins University Press, 1975.

Stewart, Frances. "A Note on Social Cost-Benefit Analysis and Class Conflict in LDC's." *World Development* 3 (January 1975): 31-39.

UNIDO. *Guidelines for Project Evaluation.* Project Formulation and Evaluation Series, No. 2, United Nations Industrial Development Organization, Vienna. New York: United Nations, 1972.

Weckstein, R.S. "Shadow Prices and Project Evaluation in Less-Developed Countries." *Economic Development and Cultural Change* 20 (1971-72): 474-94.

Cost-Effectiveness Analysis

PREREQUISITE TOOLS

None.

USAGE

PURPOSE

Cost-effectiveness analysis evaluates the *effectiveness* relative to the costs of alternative *systems*.

USES

Cost-effectiveness analysis is used to:

1) Evaluate alternative means for achieving specified ends, e.g., alternative components of a system or project design.

2) Evaluate and compare alternative projects or systems for the purpose of selecting the most cost-effective alternative.

3) Analyze the trade-offs in varying the size, complexity, or scope of a design, e.g., estimating the cost of increased effectiveness.

KEY DEFINITIONS

1) The *effectiveness* of a project or system is the degree to which the project or system design objectives are achieved.

2) *Project efficiency* is the ratio of project outputs to inputs, e.g., the production rate for a given resource utilization rate.

3) A *system* is a collection of components which interact to achieve a common function.

SHORT DESCRIPTION

Cost-effectiveness analysis is a crucial step in a systems analysis strategy. After deciding on objectives, identifying alternative means to achieve the desired ends, and establishing criteria for evaluation, components are selected which maximize cost-effectiveness. Costs and effectiveness are central to the evaluation and design of systems or projects.

The criteria are used in one of two ways to rank alternatives:

1) By least-cost, considering only those alternatives which achieve the specified minimum level of effectiveness.

2) By maximum effectiveness, in which all alternatives have been designed so as not to exceed a specified maximum resource requirement.

Cost-effectiveness analysis is similar to cost-benefit analysis (CBA, page 212) except that the non-monetary performance of the project is estimated.

ADVANTAGES

1) Cost-effectiveness analysis ranks alternatives by a process which is accessible to critical examination, in contrast to intuitive or committee decision-making processes. The technique provides a framework for systematic decision making and "efficient employment of the knowledge, judgment, and intuition of available experts" (Quade, 1968, page 32).

2) While the benefits accruing from a project are often not measurable (particularly in monetary terms), indexes of effectiveness can always be developed from project goal statements.

3) In contrast to *project efficiency* measures, e.g., the benefit-cost ratio (BCR, page 194) and the internal rate of return (IRR, page 200), cost-effectiveness analysis compares the relative achievement of goals.

4) Because cost-effectiveness analysis is a carefully structured approach, the process leading to a decision may be retraced; and new knowledge or different subjective judgments can be used to update recommendations.

LIMITATIONS

The analyst must necessarily limit the scope of a cost-effectiveness study, which may lead to sub-optimization. The most cost-effective alternative may not be the best choice when the larger problem situation is considered.

The complexity of the analysis increases significantly if more than one future situation (contingency) is examined (see Contingency Analysis, CGA, page 147). Consequently, analysts and decision makers tend to restrict the analysis to the most likely contingency.

Projects with different objectives cannot be compared using cost-effectiveness analysis because the scales of effectiveness will differ significantly. Cost-benefit analysis (see CBA, page 212), although limiting the choice to financial or economic criteria, permits a comparison of these projects if benefits can be valued monetarily.

Ranking projects can be inconclusive when more than one measure of effectiveness applies. Often, determining a suitable measure of effectiveness is difficult, if not impossible (e.g., evaluating goal achievement of social service programs).

Cost-effectiveness focuses only on the system and its performance, in contrast to cost-benefit analysis which includes benefits and costs accruing to other elements in the environment. This may not promote better decisions, but cost-benefit analysis alerts the decision maker to these issues.

Cost-effectiveness analysis may be used to choose among projects only if they are alternative means to the same ends. Otherwise, a common measure of effectiveness cannot be identified for evaluating each alternative.

REQUIRED RESOURCES

LEVEL OF EFFORT

The major task in cost-effectiveness analysis is gathering information to measure effectiveness and cost. Once these data are obtained and transformed into quantitative measures, the analysis is essentially complete.

SKILL LEVEL

Considerable judgment must be applied to determine measures of effectiveness and to apply them in the analysis. This is never strictly a mechanical process of translating goals into measures, although construction of a system model is desirable for analyzing performances of large complex systems (or projects).

TIME REQUIRED

A cost-effectiveness analysis may take several days if many projects are to be compared on more than one measure of effectiveness. The actual time required depends primarily on the availability of appropriate information.

DESCRIPTION OF TOOL

SUPPLEMENTAL DEFINITIONS

1) *Resource analysis* is the "process of systematically determining the economic resource impact of alternative proposals for future courses of action" (Fisher, 1968, page 124). It includes not only estimating the direct costs, but measuring the drain on economic resources which could result if various alternatives were selected and implemented, e.g., diverting essential raw materials and skilled manpower to a project.

2) *Sensitivity analysis* is a process of varying the estimated values of selected parameters in the design in order to determine the sensitivity of results to the uncertainty of the estimate. For example, the variation in total system cost is determined for selected values of key system specifications such as size, responsiveness, or reliability.

REQUIRED INPUTS

The objectives must be established (see Objective Trees, OBT, page 49). Alternative means will have to be specified, e.g., various project approaches have been identified.

Cost data must be available to determine the cost for each alternative.

TOOL OUTPUT

Cost-effectiveness analysis presents a rank-ordering of alternatives to aid decision makers. It does not select the best alternative unless non-quantifiable variables such as the political, social, and cultural implications are to be ignored—an unlikely situation for development planning. Consequently, the results of the cost-effectiveness analysis represent one part of the total information desired for project selection.

If project effectiveness is not identifiable as a single measure, the analysis may result in several rankings of effectiveness vs. cost, all of which are presented to the decision maker.

IMPORTANT ASSUMPTIONS

The results of a program or project can be evaluated using a criterion which measures the achievement of objectives. The objectives are determinate, stationary, and stable over the life of the project and consensual among the decision makers (see Objective Trees, OBT, page 49). Although these assumptions are not limiting, they should caution the decision maker and analyst against naively applying a cost-effective criteria without considering their implications.

METHOD OF USE

GENERAL PROCEDURE

1. Given the project or system goals, identify the measure of effectiveness.

1.1 Translate each goal into measurable sub-objectives (see Objective Trees, OBT, page 49).

1.2 Repeat 1.1 until quantifiable sub-objectives are identified.

1.3 Select quantifiable objectives which characterize the effectiveness of the project/system.

2. Construct an effectiveness scale.

2.1 Determine the units of measurement, e.g., passenger-miles per hour, extension contact hours per farmer.

2.2 If necessary, use a dimensionless index to compare subjective estimates of effectiveness.

2.3 Identify the range of the effectiveness scale, typically 0 to 1 for an index (see Rating Scales, RTS, page 29).

3. Give alternative means and evaluate their effectiveness.

3.1 When feasible, construct an analytical model to compute effectiveness estimates for each alternative (see Computer Simulation Models, CSM, page 120).

3.2 When mathematical modeling is not feasible, estimate the effectiveness subjectively. Pooled expert judgments may be used (see Delphi, DLP, page 168), or empirical data may be obtained (either by experiment or pilot study).

4. Determine costs by making a resource analysis of the alternatives.

4.1 Determine a basis for costing which is comparable across all alternatives.

4.2 Identify direct costs, both initial and recurrent, and costs associated with making resources (e.g., raw materials and manpower) available to the project (see Cash Flow Analysis, CFA, page 177).

4.3 If the costs are distributed differently in time for each alternative, discount all costs to determine the present worth (see Discounting, DIS, page 184).

5. Rank-order the alternatives.

5.1 Compute the ratio of effectiveness to cost for each alternative.

5.2 Plot effectiveness vs. cost (optional).

5.3 Determine the cut-off levels for considering alternatives:

a) If a minimum level of effectiveness is required, ignore all objectives which fall below this level. If none exceed the level, either change the specification or identify new alternatives.

b) If a maximum level of cost is permitted, ignore all alternatives which exceed this limit. If none has acceptable costs, consider scaling down the scope of the alternatives or identify less costly means.

5.4 Rank-order the remaining alternatives using the ratio of effectiveness to cost. If two or more alternatives have identical ratios, select the most effective or least costly depending on whether a) or b) holds.*

6. Test the sensitivity of the rankings.

6.1 Select a variable (cost or effectiveness) for which the estimate is most certain.

6.2 Using either the analytical model or an experimental design, estimate how a small change in this variable will affect the subsequent computation.

6.3 Repeat 6.2 for several values included in the likely range of the variable.

*Specifying both a minimum level of effectiveness and a maximum acceptable cost may lead to an under-specification of the system. The designer may fail to identify the most cost-effective alternatives.

FIGURE 1
Reliability and Acceptance Rates for Alternative Means of Birth Control

Alternative Means	Probability of Preventing Pregnancy	Average Acceptance Rate for Specific Population	Effectiveness
Male contraceptives	.90	70%	63
Female contraceptives:			
Hormone pills	.95	80%	76
Intrauterine devices	.90	50%	45
Male sterilization	.99	5%	5
Female sterilization	1.00	20%	20

FIGURE 2
Cost Analysis of Alternative Means of Birth Control

Alternative Means	Couple Year(s) of Protection	Estimated Method Cost[1]	Protection Cost Per Year
Male contraceptive	0.0083/condom[2]	U 4.2/condom	U506
Female contraceptive			
Oral	0.0667/cycle[3]	U 30/cycle	U449
Intrauterine	3/IUD[4]	U 60/IUD	U 20
Male sterilization	10[5]	U450	U 45
Female sterilization	10[6]	U900	U 90

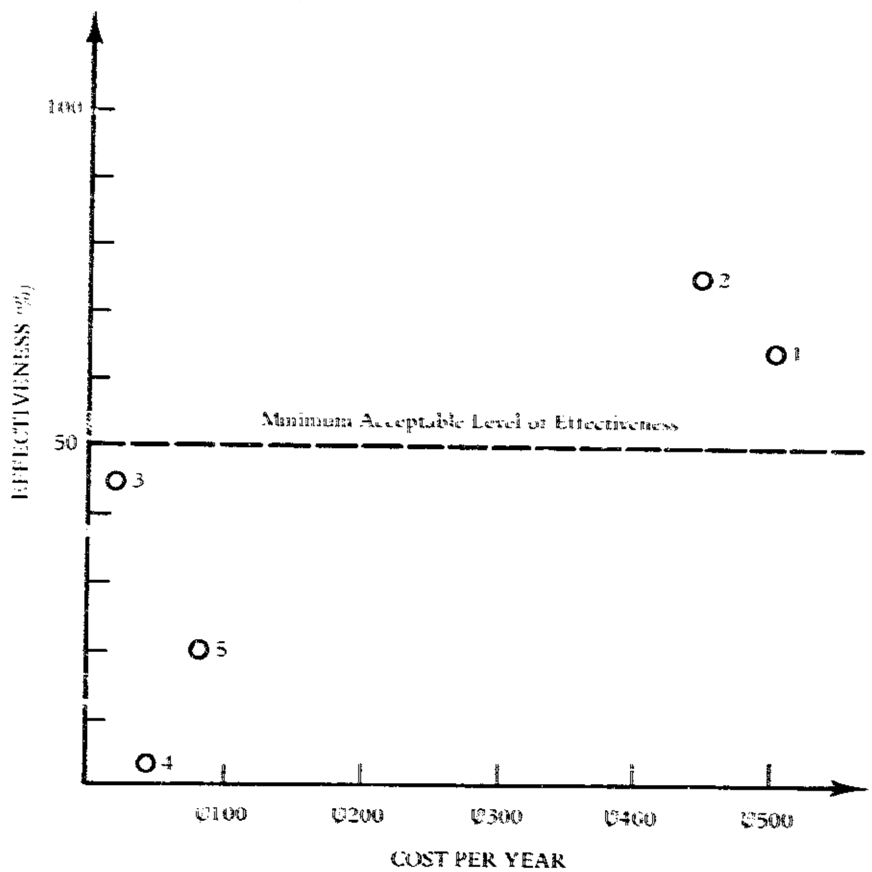
1. U = Unis = the national currency of Temasek.
2. Assuming an average use of 120 condoms per year.
3. Assuming 15 cycles are required each year (including wastage).
4. Assuming each IUD inserted is retained for an average 3 years.
5. Assuming 10 years from average age of sterilization (35) to onset of menopause.
6. Assuming same average age of wife of the man sterilized.

FIGURE 3
Cost-Effectiveness of Alternative Birth Control Means

a) Effectiveness-Cost Ratio

Alternative	Yearly Cost ₵	Effectiveness %	Ratio: Effectiveness to Cost
1. Male contraceptives	506	63	0.12
Female contraceptives			
2. Oral	449	76	0.17
3. IUD	20	45	2.25
4. Male sterilization	45	5	0.11
5. Female sterilization	90	20	0.22

b) Plot of Effectiveness vs. Cost



6.4 Present the sensitivity analysis results to the decision maker as a range of variation in the effectiveness to cost ratio or as a box which indicates the uncertainty on the plot of effectiveness vs. costs.

EXAMPLE

The Temasek Family Planning Council proposed to examine the cost-effectiveness of various means of birth control in use in Temasek. The objective of the project was to determine the best means of birth control for funding. Two criteria were identified: the reliability of the particular method and the percentage of the population accepting that method. The effectiveness was defined as the product of reliability and rate of acceptance (see figure 1).

The next step was to analyze the costs of the alternatives. The measure adopted was the equivalent Couple Year of Protection for each technique (Edmonds, 1975). For example, data indicated that each couple used an average of 120 condoms per year. Then each condom afforded 0.0083 CYP. Similarly, a sterilization operation would protect a couple for the remaining child-bearing years. The corresponding CYP was computed by subtracting the average age at sterilization from the average age for onset of menopause (see figure 2).

The protection cost per year of each birth control technique was computed by dividing the estimated method cost* by the CYP. On a cost basis alone, there were vast differences in the resources required to provide a year of protection by various alternatives.

The costs were compared to the estimated effectiveness (see figure 3). Computing the ratio of effectiveness to cost revealed that an intrauterine device was by far the most cost-effective technique. However, the level of effectiveness was estimated at less than 50% (due to the low rate of acceptance). If 50% were taken as the minimum level of effectiveness, then only oral contraceptives and condoms would be considered.

This analysis considered only the means of birth control. A cost-effectiveness analysis of a birth control program would ultimately have to examine the effects of using various techniques on the birth rate vs. the infrastructure necessary to deliver the techniques. Unfortunately, such an analysis is complicated by 1) the delay in observable changes in birth rate and 2) the multitude of alternative explanations for changes in birth rate. The problem in evaluating cost-effectiveness of these programs is described in Schultz (1972). In an earlier paper, Schultz (1967) formulated an economic model of family planning in order to measure benefits vs. costs.

*These costs ignore the infrastructure required for delivering the various techniques. Although this could be incorporated into each method cost as an overhead component, a separate analysis of the means of delivery is more appropriate.

THEORY

Cost-effectiveness derives from cost-benefit analysis (Rowen, 1969). Defense Department analysts realized that valuing the benefits of weapon systems was not feasible and looked for other measures of system performance. The theoretical analysis of system models and tactical and strategic plans followed (Quade and Boucher, 1968). The technique has been applied to policy planning and project design in fields like social services. The formidable task of valuing benefits is circumvented by using nonmonetary effectiveness scales to compare alternatives.

The role of resource analysis and sensitivity analysis in cost-effectiveness studies is presented by Quade and Boucher (1968). DeNeufville and Stafford (1971) address additional theoretical issues, such as determining the optimum system effectiveness as a function of the cost.

Krueckeberg and Silvers (1974) give an excellent description of cost-effectiveness analysis applied to urban planning and the theoretical basis for selecting among alternative projects using the effectiveness-cost ratio.

BIBLIOGRAPHY

DeNeufville, R., and Stafford, J.H. *Systems Analysis for Engineers and Managers*. New York: McGraw-Hill, 1971.

Edmonds, Scott. "Estimated Cost of Contraceptives by Method." USAID Internal Memorandum HPP/PFP. Thailand, January 23, 1975.

Fisher, G.H. "Resource Analysis." In *Systems Analysis and Policy Planning*, edited by E.S. Quade and W.I. Boucher. New York: American Elsevier, 1968, pp. 124-37.

Krueckeberg, Donald A., and Silvers, Arthur L. *Urban Planning Analysis: Methods and Models*. New York: John Wiley and Sons, 1974.

Quade, E.S., and Boucher, W.I., eds. *Systems Analysis and Policy Planning: Applications in Defense*. New York: American Elsevier, 1968.

Rowen, Henry. "Objectives, Alternatives, Costs and Effectiveness." In *Program Budgeting and Benefit-Cost Analysis*, edited by Harley H. Hinrichs and Graeme M. Taylor. Pacific Palisades, Calif.: Goodyear Publishing, 1969, pp. 83-93.

Schultz, T. Paul. *An Economic Model of Family Planning and Fertility*. RAND Corporation Paper P-3862, November 1967.

Schultz, T. Paul. *Effectiveness Evaluation of Family Planning*. RAND Corporation Paper P-4890, September 1972.

IX

Planning, Controlling, and Evaluating Projects

Program Planning Method
IDEALS Strategy
Planning, Programming, and Budgeting
Critical Path Method
Gantt Charts
Logical Framework

Several techniques have been selected which do not fall exclusively within any of the major purpose categories. Two (Program Planning Method and IDEALS Strategy) are comprehensive approaches to project design and implementation. A formal system for planning and management (Planning, Programming, and Budgeting) is also described.

Successful implementation and management of complex projects depend on careful attention to details in the planning stage. Diagramming the sequence of necessary activities (Critical Path Method) and scheduling according to available resources (Gantt Charts) assist this process.

Evaluation of a development project must begin with design. The final technique (Logical Framework) is a test approach to planning, documenting, and evaluating projects. Attention is directed to the logical assumptions and verifiable indicators of project achievement.

All these techniques are unified in their attention to planning for implementation, stressing systematic analysis, and emphasizing results.

Program Planning Method

PREREQUISITE TOOLS

Nominal Group Technique (NGT, page 14).

USAGE

PURPOSE

Program Planning Method provides a comprehensive approach to:

1) Identify and define problems.
2) Specify program alternatives to solve the problem.
3) Select and detail programs.

USES

The Program Planning Method is used to:

1) Coordinate the best use of experts, decision makers, and client/citizens in the planning process.

2) Plan programs in different fields, such as health, urban, and educational planning.

3) Develop consensus in group decision making when people from widely different backgrounds are involved.

4) Legitimize decisions in the minds of the public in order to increase public acceptance of programs.

SHORT DESCRIPTION

Program Planning Method is a systematic and structured planning strategy involving clients or consumers, experts, and decision makers in group processes. The Nominal Group Technique (NGT, page 14) is used in three stages. First, a number of client-problems are identified and rank-ordered. Second, this list is used to generate possible solutions. Resources needed to implement the solution are also listed. Third, the group arrives at the final program.

ADVANTAGES

The originators of the Program Planning Method strategy (Delbecq and Van de Ven, 1971) claim that it:

1) Organizes client, consumer, or community participation.

2) Increases the legitimacy of the program in view of the recipients' (clients/citizens) involvement.

3) Decreases potential resistance to the implementation of the program.

4) Increases the program's effectiveness because all concerned parties participate in the design.

5) Facilitates proper problem identification and reduces the chances of solving the wrong problem.

6) Facilitates the use of outside experts in the planning process.

7) Incorporates the advantages of the Nominal Group Technique (see NGT, page 14).

LIMITATIONS

1) The participation of consumer and client groups may be unfeasible either financially or logistically.

2) The role of the group leader is more important than in single applications of the Nominal Group Technique. The same leader is often in charge of three different groups and thus can control the success of the exercise.

3) Client/citizen participation may have a negative effect on the planning process, e.g., premature expectations may arise.

4) The highly structured nature of the Program Planning Method may stifle effective participation. (See Nominal Group Technique, NGT, page 15, for related limitations.)

REQUIRED RESOURCES

LEVEL OF EFFORT

Members of client groups, experts, and other concerned people must be identified, and the group sessions must be arranged and conducted. This may pose problems of logistics and requires planning.

SKILL LEVEL

Considerable skill is required to direct the Program Planning Method. The group leader must be able to 1) understand and break down the planning process into a discrete series of workable phases; 2) identify and integrate the target reference groups in each phase; and 3) direct the groups so that they perform effectively.

TIME REQUIRED

The Program Planning Method requires three or more sessions of one-half day each. There may be a gap of a few days between the sessions. Lead time is needed for organizing groups and meetings.

SPECIAL REQUIREMENTS

The Program Planning Method strategy requires:

1) A meeting room where groups can cluster around a table.

2) Index cards to record the group members' ideas and preferences.

3) Flip charts with large sheets of paper, marking or felt pens, and tape.

DESCRIPTION OF TOOL

DEFINITIONS

1) A *solution component* is the part of a program that is proposed as the solution, e.g., a mobile medical unit in a health care program.

2) *Rank-ordering* is the process of weighing one item against others and then ordering the items by weight on a scale such as importance or priority.

REQUIRED INPUTS

Program Planning Method requires a knowledge of:

1) The problem area, e.g., urban renewal, health care delivery.

2) The target area, e.g., a region, a community, or an ethnic group.

The method also requires that user groups, experts, and decision makers participate.

TOOL OUTPUT

1) A list of consumer or client problems ordered to indicate priorities.

2) Specification of the problem to be solved.

3) Specification of the program designed to solve the problem.

IMPORTANT ASSUMPTIONS

Program Planning Method assumes that problem identification is necessary before planning a program. The best qualified people to identify the problem are the groups affected by potential programs or current inadequate programs. These people are brought together with planners and program personnel to identify problems and to rank them.

Program Planning Method is also based on assumptions regarding change processes in organizations, and the best use of experts in the process (see Delbecq and Van de Ven, 1971).

METHOD OF USE

GENERAL PROCEDURE*

1. Organize the client group.
   - 1.1 Identify a cross section of clients or consumers in the program area. Include members of different ages, locations, technical abilities, etc., depending on the nature of the problem or service. For example, in the development of an employment service, the client group would include potential employers, the currently unemployed, the currently employed, and retired people.
   - 1.2 Select a group (usually between 30 and 50 people) that will represent the client population.

*The procedure recommended by Delbecq (1971) should be followed closely by the program planner and group leader.

1.3 Organize a group meeting to discuss common problems in the program area.

2. **Identify problems.**
   2.1 Divide the group into subgroups of six to nine members according to a common characteristic, e.g., age.
   2.2 Indicate that the decision makers want to understand clients' views.
   2.3 Instruct the group in Nominal Group Technique (NGT, page 14). Stress that the meeting should produce a list of problems—not solutions.
   2.4 Request members to list "personal" problems in the program area on one side of the index card and "organizational" problems on the other side. For example, a client in the improvement program for an employment service may list "I do badly in oral interviews" as a personal problem and "the job opportunity list comes too late" as an organizational problem.
   2.5 Let the members list ideas silently for about 30 minutes.
   2.6 Record the generated items on a flip chart—one for each subgroup.
   2.7 Using the Nominal Group Technique rank-ordering voting procedure, select the top five priority items on the flip chart.
   2.8 Explain that some members will participate further in development of the program. Have them select three or four representatives.

3. **Generate program ideas.**
   3.1 Identify external technical and organizational experts whose skills relate to the listed priority items. Identify internal experts from the principal organization connected with implementation of the program.
   3.2 Arrange a group meeting to include these experts and the group's representatives. Explain Nominal Group Technique to them.
   3.3 Prepare and display the list of priority problems generated by the client group and explain each item.
   3.4 Instruct the group to prepare a list of *solution components* and the resources required to implement them. The list should be in two parts: 1) those items currently available and easily procured (written on one side of an index card), and 2) those items to be developed (written on the other side of the card).
   3.5 Allow the members to write silently for about 40 minutes.
   3.6 Compile the lists and display them on a large flip chart.
   3.7 Following a five to ten minute break, reassemble the group and discuss each item briefly.
   3.8 Using the rank-ordering voting procedure, select the components and resources considered to be essential.
   3.9 Explain the rest of the Program Planning Method and have participants elect representatives for further sessions.

4. **Generate specific program alternatives.**
   4.1 Identify the key administrators and resource controllers who were listed by the second group.
   4.2 Present the program ideas and instruct the group to work out specific alternative programs from the idea list.

5. **Design the program.**
   5.1 Organize a meeting of representatives from client and expert groups, decision makers, and resource controllers.
   5.2 Present details of alternative programs from step 4 and discuss them briefly.
   5.3 Conduct nominal group voting to arrive at the final design.
   5.4 If a consensus or significant agreement cannot be reached, repeat steps 4 and 5 after a few days delay.
   5.5 The final solution should be satisfactory to all concerned.

EXAMPLE

Though Program Planning Method has only recently been developed, its use has been varied. For example, it was used by the Governor's Task Force for Planning Health Services in the State of Wisconsin in 1972. It was also used by a health planning agency in Texas in 1973 to design health service programs.

THEORY

Delbecq and Van de Ven (1971) developed the Program Planning Method at the University of Wisconsin's Graduate School of Business. The method extends experimental and field research on the use of the Nominal Group Technique to planning processes.

The technique is rooted in empirically derived theories of organizational change processes which specifically address the scheduling of client participation and the utilization of multi-disciplinary expertise (see Delbecq, Van de Ven, and Gustafson, 1975).

BIBLIOGRAPHY

Delbecq, André L., and Van de Ven, Andrew H. "A Group Process Model for Problem Identification and Program Planning." *Journal of Applied Behavioral Science* 7 (November 1971): 466-92.

Delbecq, André L., and Van de Ven, Andrew H. "Nominal Group Techniques for Involving Clients in Program Planning." *Academy of Management Proceedings* (August 1970).

Delbecq, André; Van de Ven, Andrew H.; and Gustafson, David. *Group Technique for Program Planning: A Guide to Nominal Group and Delphi Processes.* Glenview, Ill.: Scott Foresman, 1975.

Van de Ven, Andrew, and Delbecq, André L. "A Planning Process for Development of Complex Regional Programs." Graduate School of Business, University of Wisconsin, 1972.

IDEALS Strategy

PREREQUISITE TOOLS

Function Expansion (FEX, page 45) and System Definition Matrix (SDM, page 67).

USAGE

PURPOSE

The IDEALS (Ideal Design of Effective and Logical Systems) Strategy provides a comprehensive approach for solving problems by specifying *systems* to achieve a desired *function*.

USES

The IDEALS Strategy can be used to:

1) Design systems and plan for their implementation.

2) Provide a conceptual framework for studying problems.

3) Generate alternative solutions to a problem.

4) Develop products or services.

KEY DEFINITIONS

1) An *ideal system target* achieves the function in the best possible manner as judged by the criteria for evaluating the system. Such systems typically require the least possible cost, the least amount of human resources, and the least time while providing maximum benefits.

2) *Regularity* is the most frequent or dominant (and occasionally the most important) condition of concern to the project design.

SHORT DESCRIPTION

The emphasis in the methodology is first on "why" and then on "how" the system operates. The function of the system is determined by using Function Expansion (FEX, page 45); and an *ideal system target* for the units or regularity which will meet the function is developed. With this ideal system target as a guide, alternative systems, which incorporate necessary irregularities, are developed which are as close to the ideal as possible. One of these is recommended for implementation, and the details are then specified using the System Definition Matrix (SDM, page 67). The process of implementation is suggested, and measures of evaluation are established.

ADVANTAGES

1) A key concept is to develop an ideal system before specifying the feasible solution. Thus, innovative and effective systems are likely to be developed, rather than patched up versions of existing systems or solutions.

2) Thinking is not inhibited by the recorded characteristics of the current system. The emphasis in IDEALS Strategy is on the function of the desired system rather than on improvement of the current system.

LIMITATIONS

1. The concept of what is ideal or optimal may be difficult for some people to comprehend and apply.

2. The function of a system may not be easily identifiable (see Function Expansion, FEX, page 45).

REQUIRED RESOURCES

LEVEL OF EFFORT

The design process often involves a group of people working on a problem. The effort required is directly proportional to the magnitude and complexity of the problem at hand. Effort is required to expand the system function, to develop an ideal system, and to recommend the feasible solution.

SKILL LEVEL

Some knowledge about the problem area is necessary to solve a problem using the IDEALS Strategy. No special skills are necessary to understand or use the approach. Repeated use of IDEALS Strategy in different contexts enhances its effectiveness.

TIME REQUIRED

The time required is proportional to the magnitude and complexity of the problem being solved. Typically, less than a week is required for preliminary design of products, more than a week for service systems involving people.

DESCRIPTION OF TOOL

REQUIRED INPUTS

The decision maker must have knowledge of the problem area and a statement of the problem at hand.

When solving a problem by the IDEALS Strategy, it may be necessary to use tools such as Brainstorming (BSG, page 3) or Cost-Benefit Analysis (CBA, page 212). Knowledge of such tools or access to an analyst may be needed.

TOOL OUTPUT

The recommendation of a solution is the primary output. The recommended system can be specified in the form of a System Definition Matrix (SDM, page 67). Use of IDEALS Strategy also provides insight into the problem.

Figure 1 gives an example of a possible output for a job information system.

FIGURE 1

Function Hierarchy for IDEALS Strategy

Function Hierarchy

1. Provide list of job opportunities
2. Communicate job opportunities to unemployed people
3. Match job specifications with applicant specification
4. Get people and jobs together*
5. Find employment for people
6. Fill vacancies in industry and government
7. Have jobs and services carried out
8. Get jobs done
9. Provide services
10. Keep economy functioning
11. Promote general welfare

*Function level selected for design of the system.

NOTE: The hierarchy lists the functions from the most unique function at the top to the most general at the bottom.

IMPORTANT ASSUMPTIONS

The IDEALS Strategy assumes that when developing alternatives, creativity is improved by focusing on function and an ideal situation rather than on the problems and limitations of the existing system. The strategy also assumes that functions can be clearly identified for all systems, and that ideal systems are conceivable. However, "ideal" implies optimization, and optimizing a system for all possible conditions is not feasible, hence the *regularity* concept.

METHOD OF USE

GENERAL PROCEDURE

1. **Determine the function.**

   1.1 The function of the system to be developed is identified by using function expansion (FEX, page 45). A hierarchy of functions is developed, and a level in the hierarchy is chosen as the appropriate function for the system.

1.2 Determine the measures or criteria of the system's effectiveness. Select those measures considered necessary and important to ensure the elimination of unnecessary constraints and conditions in the design.

2. **Develop ideal systems targets.**
   2.1 First, try eliminating the function chosen in step 1 to review the necessity of the function and to make certain that only required systems are developed. Preview the function hierarchy and check to see if a different (usually higher) function level may be more appropriate.
   2.2 Identify regularities, which are the primary concern or the most frequent characteristics of the system. The focus on regularities addresses the consistency of the ideal situation. For example, in an irrigation project most of the dry land is on the north side of the river. The regularity concept argues for ignoring the opposite side in initial planning. When an educational system is being designed for a region where a small part of the population is bilingual, the regularity concept recommends that planning begin with instruction given only in the language spoken by the majority.
   2.3 Develop guidelines for the ideal system target based on the identified function and agreed upon measures of effectiveness. For example, some guidelines developed for the design of a fertilizer distribution system may be "least cost of transportation," "most equitable distribution," and "least consumption of fertilizer per unit of food produced." Differentiate between the ideal concepts that are feasible and those that are not currently feasible due to technical or theoretical considerations. Select only those ideal values that are feasible.
   2.4 From the guidelines above, develop appropriate ideal systems. Select one as the ideal system to be the target for subsequent design.

3. **Develop the system to be recommended.***
   3.1 Obtain information concerning the questions raised during the development of the ideal system target. Experiments or analytical calculations may be necessary. The purpose is to determine those facets of the ideal system which need to be altered and those which can remain as they are.

*The ideal system target developed relates only to the regularity conditions. This step takes care of the irregular conditions while staying as close to the ideal system target as possible.

FIGURE 2
Identifying Measures of Effectiveness, Regularities, and Ideal Concepts

a) Measures of Effectiveness (Criteria)

Amount of delay in getting employer and applicant together
Cost of arranging the meeting (for employer, for applicant, for the agency)
Ratio of vacancies to applicants
Ratio of number job applicants matched to number of applicants
Number of interviews per successful match
Total number of clients served

b) Regularities

Applicants come to agency requiring jobs
Applicants are unemployed
Exception: applicants want reassignment
Employers come to agency expressing need for applicants
Exception: agency to canvas prospective employers
The output of the agency is the arrangement of interviews
Exception: physically bring together two parties or be present at the interview

c) IDEALS Concepts

No delay in finding jobs for applicants or applicants finding jobs
Obtain complete specification of applicant skills*
Obtain complete specification of job requirements*
All jobs will have broad specifications
All applicants have marketable skills
All interviews result in jobs
All vacancies are reported
Minimum effort by service in soliciting jobs
Minimum effort by service in finding applicants

*At no cost

FIGURE 3

Preliminary System Definition Matrix for a Job Information System

SYSTEM DIMENSIONS[†]

SYSTEM ELEMENTS	Fundamental	Rate	Control	Interface
Function	To find job vacancies and to maintain records	Find more vacancies than applicants		
Inputs	Information about job openings	Daily reports	Cost per job to be low, daily update	Other employment agencies
Outputs	Reports of job openings presentable to applicants	Daily reports	Weekly update and check of reports	Interview systems, applicant information system
Sequence	Gather information, order and arrange, retrieve, match	Number of jobs per day		Applicant information system
Environment	Economic: service sector, industrial sector. Political: gain support for agency, public cooperation		Maximum public cooperation	Unemployment insurance
Physical Catalysts	Data gathering system records, files, storage/retrieval systems computer			
Human Agents	Liaison officers, employer representation, job counselors	Daily and evening job counseling	Rotate evening shifts per schedule	
Information Catalysts	Government contracts, list of firms, newspapers, trade and professional journals, stock-exchange lists			Applicant information system, other employment agencies

NOTE: See System Definition Matrix (SDM, page 67) for clarification of terminology.

[†]The future state is omitted in this example but is part of the final design process.

3.2 Identify alternative systems. Group processes, such as Nominal Group Technique (NGT, page 14), may be used. Selecting a feasible system close to the ideal target involves predicting how the system will perform as well as evaluating and comparing different suggestions.

4. **Recommend implementation procedures.**

This step may involve testing the effectiveness of the system. Training personnel may be required. Establish performance measures for the system and guidelines for future changes in order to effect ongoing improvements in the system.

EXAMPLE

Developing an employment service in a region where unemployment is high is discussed in Function Expansion (FEX, page 45). The function hierarchy developed is given in figure 1. The function level selected in step 1 is "to get people and jobs together." This selection allows maximum flexibility in generating alternative ideal systems which achieve the function. Criteria for evaluating the system are given in figure 2a.

In step 2, regularities and exceptions in the system are identified (see figure 2b). A group process is used to generate the criteria and regularities. Guidelines for ideal systems are developed and listed (figure 2c). Ideal systems as targets are then developed. From the list of criteria and regularities, the following target systems are identified:

1) System to find the maximum number of vacancies.
2) System to assess marketable skills of applicants.
3) System that eliminates interviews.

The first two target systems reflect the need to satisfy criteria, e.g., having a high ratio of vacancies to applicants.

The third system bypasses the function level "getting jobs and people together" to arrive at the function level "fill vacancies" in the function hierarchy. That is, the ideal system for the function level selected, "get people and jobs together," may be a system which accomplishes the higher function of "fill vacancies" as shown in figure 1.

System 1 is selected as target system. Part of this system is another system where information about available jobs is obtained. A preliminary system definition matrix (SDM, page 67) partially specifies the feasible system (figure 3).

An example of applying the strategy to information system design is documented in Nadler et al. (1975). Other examples may be found in health education and industrial applications literature.

THEORY

The IDEALS Strategy was developed by Nadler (1967) and has been used extensively in industry, commerce, public service agencies, and government. A detailed discussion of the strategy is given in Nadler (1970).

BIBLIOGRAPHY

Nadler, Gerald. *Work Design.* Homewood, Ill.: Richard D. Irwin, 1970.

Nadler, Gerald. *Work Systems Design: The IDEALS Concept.* Homewood, Ill.: Richard D. Irwin, 1967.

Nadler, Gerald; Johnston, J.; and Bailey, J. *Design Concepts for Information Systems.* Monograph series, Computer and Information Systems Division, AIIE, 1975.

Planning, Programming, and Budgeting

PREREQUISITE TOOLS

Cost-Benefit Analysis (CBA, page 212).

USAGE

PURPOSE

A Planning, Programming, and Budgeting (PPB) strategy makes evaluation part of the program selection process by clearly defining *goals* and evaluating projected outputs prior to selecting a specific program.

USES

PPB may be used to:

1) Plan a program with emphasis on its goals and on how well each alternative meets those goals.

2) Prepare a budget statement that lists expenditures and evaluates outputs according to goals.

3) Choose from among several projects which meet program goals when resources are limited.

SHORT DESCRIPTION

PPB is a comprehensive planning strategy. It structures the decision-making process into identification of goals, development of programs to meet those goals, and evaluation of alternative program costs and outputs (or benefits).

First, the *policy* goals of an agency are defined, and then programs are developed to meet the goals. Then, techniques like Cost-Benefit Analysis (CBA, page 212) and Cost-Effectiveness Analysis (CEA, page 219) may be used to determine the resource costs and the projected outputs (benefits) of the program. Estimates of future resource costs and output are specified. This information is then included in a budget statement with the programs arranged by policy goals. Decisions between alternative programs may be made based on the planning, programming, and budgeting goals and a cost-benefit analysis.

ADVANTAGES

1) PPB represents a transformation of budget planning based on resources and input requirements to function-output oriented budget planning and decision making. This approach has advantages for government budget analysis. Resource needs are not merely listed under a department heading; they are grouped by programs where required. This allows a decision maker to evaluate the costs of each program category relative to overall goals.

2) PPB allows the decision maker to re-evaluate ongoing programs each budget year. Automatic continuation of funding is less likely, due to the improved feedback of performance.

LIMITATIONS

1) The initial step of setting goals can be difficult, especially for large government agencies. Because of the

difficulty in reaching agreement, the final goals are often too general to be used for developing or evaluating programs.

2) The necessary data collection is time-consuming. In addition, many decision makers feel that too much information is presented for effective evaluation.

3) Many variables, particularly the outputs, cannot be adequately quantified in a uniform unit measure. In social programs, this is especially difficult.

4) It is difficult to show the relationships of program components to more than one goal in the budget statement.

5) The PPB approach gives the tasks of program development and evaluation to the same decision maker(s). Hence, output measures most favorable to the program evaluation can be selected.

REQUIRED RESOURCES

LEVEL OF EFFORT

PPB is a comprehensive planning technique, and more effort is required as the complexity of the system increases. Decision makers will often be engaged in a continuous effort to define goals, develop programs, and evaluate costs and outputs. When this happens, it is necessary to collect data on costs and outputs for the next budget statement.

Somewhat more effort may be required than simple budgeting and bookkeeping; however, PPB may be considered an alternative to normal budgetary control.

SKILL LEVEL

The user needs a knowledge of systems analysis techniques like Objective Trees (OBT, page 49) and Cost-Benefit Analysis (CBA, page 212). Skills in accounting methods and cost data collection may also be necessary.

TIME REQUIRED

Time required depends on the complexity of the system to be planned, programmed, and budgeted. In many agencies, this is a continuous process.

SPECIAL REQUIREMENTS

A PPB system may be done on a computer, as in other cost-accounting systems. In large organizations, computerized data-handling may be essential for effective planning, programming, and budgeting.

DESCRIPTION OF TOOL

DEFINITIONS

1) A *program category* is a system category under which specific projects, or program sub-categories, are developed; e.g., development of agriculture or health services.

2) A *program sub-category* refers to the specific projects considered under a program category; e.g., a sub-category of agricultural development is hybrid seed research.

3) *Program elements* are the resources or inputs needed to carry on a project.

REQUIRED INPUTS

When developing goals and measurable objectives, the agency or unit responsible for planning must understand the organization's purpose and how other agencies cooperate within the organization.

Knowing the resource requirements and the resources available and having access to cost data are necessary.

TOOL OUTPUT

There are four areas of information for decision making:

1) The defined goals of the agency.

2) Alternative programs to meet those goals.

3) An evaluation of the costs and benefits of each alternative.

4) A means for measuring the results of the program selected for future evaluation.

IMPORTANT ASSUMPTIONS

PPB assumes that well-defined goals can be agreed upon. Using ambiguous goal statements weakens the planning process and the attempts to measure program results versus program goals.

The results of a program must be measurable. However, in social programs such as health care, measuring the increased health level as a result of the program may be difficult, if not impossible. Yet, the planning process assumes that the future output of a program can be adequately estimated.

A project leader, or agency head, must contribute to the presentation of well-defined goals for agency programs and the evaluation of all program results each budget year.

METHOD OF USE

GENERAL PROCEDURE

The procedure is divided into three stages: 1) planning, 2) decision making/implementation, and 3) review.

Planning Stage

1. **Define the goals of the organization or institution.**
   1.1 Determine the type of programs to be developed, and help evaluate the results of the programs. Use techniques such as Function Expansion (FEX, page 45), Objective Trees (OBT, page 49), and Intent Structures (INS, page 55) to identify goals.
   1.2 Initially, state goals in broad terms. Then define each phrase in the goal statement in more detail.

2. **Develop programs to achieve goals.**
   2.1 Gather relevant information. Program development requires extensive knowledge of the relevant social and economic system and of the particular problem to be solved. A wide range of information gathering may first be required. Explore theories on the subject and interview experts. Other tools, such as Delphi (DLP, page 168) or Morphological Analysis (MPA, page 10), may be useful.
   2.2 Use this information to develop programs that promise to achieve the defined goals. List programs by types into different *program categories*. When a program involves more than one project, *program sub-categories* will be necessary (see figure 1).
   2.3 Break the program categories or sub-categories into *program elements*, the specific resources needed to carry on the program.

3. **Estimate needed resources (inputs).**
   3.1 Estimate the cost of each program element and determine the average cost per project.
   3.2 Discount all future costs to the present for analysis and comparison on the same basis (see Discounting, DIS, page 184).

4. **Estimate outputs and benefits for each program category.**
   Determine a unit measure of the outputs. For example, an education program category requires a unit measure to estimate the value of a college education, e.g., dollars, number of persons receiving a degree, or number of graduates employed. Information on measuring outputs (benefits) can be found in Cost-Benefit Analysis (CBA, page 212) and the Logical Framework (LGF, page 260).

FIGURE 1
Goals and Programs for the Federal Economic Development Administration

Goal: Economic Development in Depressed Areas
Specific Goal: Increased Jobs in Rural Depressed Areas

Program Categories
A. Education
B. Public Works
C. Business Loans
D. Planning Grants

Program Sub-categories (for Program Category B)
B. Public Works Projects
1. Water/Sewer
2. Industrial/Commercial
3. Other facilities

Program Elements (for Sub-Category B.1)
A. Water/Sewer Engineering Plans
B. Construction material
C. Construction labor

5. **Evaluate program categories (or sub-categories).**
   5.1 Determine which program provides the most outputs for the least cost using cost-benefit analysis.
   5.2 Determine which program best meets the goals of the agency. This goal-related criterion for evaluation distinguishes PPB from a purely economic analysis (as in cost-benefit analysis). Although a number of programs may have a favorable benefit-cost ratio (see BCR, page 194), some programs achieve the stated goals better than others.

Decision Making/Implementation Stage

In the decision-making/implementation stage, the information from the planning stage is presented to the decision maker. The information will include the general and specific goals of the agency, possible program categories, sub-categories and program elements, an analysis of program costs and benefits, and an evaluation of how the program outputs achieve the goals of the agency.

6. **Select program categories and elements.**
   6.1 Evaluate the above information and determine which projects and programs are to be implemented.

6.2 Set priorities and, if necessary, defer implementation of some programs to the next year (e.g., if there are budget constraints).

Review Stage

7. **Monitor outputs.**

7.1 Once the program is funded, set up a mechanism to measure program outputs. The unit measures have been established in step 4, so a system of continuous data collection is needed.

7.2 Determine multiple indicators which may be useful in reviewing program outputs in order to verify the results. An indicator will seldom cover all outputs. These data will be used to evaluate the actual results of the program and will be used in future budget analysis.

8. **Develop a computer model of costs and outputs (optional).**

With the information gathered in steps 1-7, a computer model can be developed to estimate changes in the cost or output data and to help evaluate future program changes. For a more detailed discussion, see Tenzer (1969).

EXAMPLE

The goals and programs for a PPB system for the Federal Economic Development Administration are given in figure 1. The program is broken down into four program categories: the public works project is divided into three sub-categories: and program elements for the water/sewer sub-category are shown.

Figure 2 presents an analysis of the second and third *program categories.* The specific goal of creating jobs has been evaluated. Program alternative B, Public Works Project, creates more jobs than alternative C, Business Loans, but at a greater cost of $2,000 per job. Most of the jobs in alternative B will last only as long as the project itself. In alternative C, more of the jobs should be for the life of the business.

Another important evaluation criterion concerns who will receive the basic benefits. Alternative B distinguishes benefits to many residents in the depressed area, particularly because of the water/sewer projects. In alternative C, the basic business loan is a direct benefit to only a small group of business people in the community. The indirect benefits (increased tax base and long-term employment) were not estimated in this example.

FIGURE 2
Analysis of Program Alternatives

Alternative Program B: Public Works Project

	Average Cost Per Project	Average No. of Jobs	Average Investment per Job
1. Water/Sewer	$1,028,000	172	$ 5,976
2. Industrial/Commercial	1,367,000	228	5,995
3. Other facilities	618,000	41	15,073
TOTAL	3,013,000	441	6,832

Alternative Program C: Business Loans

Average Cost Per Project	Average No. of Jobs	Average Investment per Job
$366,000	75	$4,880

SOURCE: Raymond H. Milkman, et al., *Alleviating Economic Distress: Evaluating a Federal Effort* (Lexington, Mass.: D.C. Heath and Co., 1972), chapter 7.

THEORY

PPB was originally developed by the executive branch of the U.S. Federal Government for agency budget preparation. It stems from the application of a systems approach to planning and management. The first task in the conventional systems analysis strategy is to identify objectives, then to find alternative means for achieving the desired ends. The systems analyst then determines measures to evaluate the alternatives and ranks the alternatives according to their effectiveness in reaching desired goals.

A systems approach merges planning, implementation, and evaluation phases in a comprehensive system design. PPB represents one manifestation of the application of this strategy to public institutions –primarily the Department of Defense. It has a particular appeal to centralized decision makers because of the appearance of increased accountability, the implied reorganization along functional lines, and the image of scientific "systems" sophistication. This latter point is illustrated by the trend toward automating PPB accounting and reporting procedures with comprehensive management information computer systems.

It is not clear, however, whether PPB really works as intended. There is considerable evidence (for the reasons cited in Limitations) that it does not (see Caldwell, 1973, and Hoos, 1972). Nevertheless, it is an important tool to understand because it has been widely acclaimed (see Hinrichs, 1969) and because it illustrates many aspects of the systems approach. The caution for analysts and decision makers is to be skeptical of any such system (including management information systems) until it is tested and evaluated on its own merits, rather than on the basis of unsubstantiated claims and promises.

BIBLIOGRAPHY

Caldwell, Kenneth S. "Practical Considerations in Evaluating the Efficiency and Effectiveness of State/Local Government Programs." First Annual Systems Engineering Conference, New York City, November 1973.

Chu, Kong. *Quantitative Methods for Business and Economic Analysis.* Scranton, Pa.: International Textbook Co., 1969.

DeNeufville, R., and Stafford, J. *Systems Analysis for Engineers and Managers.* New York: McGraw-Hill, 1971.

Hinrichs, Henley H. "Case 3: Peace Corps: Program Structure, Objectives and Evaluation Criteria." In *Program Budgeting and Benefit-Cost Analysis,* edited by H.H. Hinrichs and G.M. Taylor. Pacific Palisades, Calif.: Goodyear Publishing Co., 1969.

Hinrichs, H.H., and Taylor, G.M., eds. *Program Budgeting and Benefit-Cost Analysis.* Pacific Palisades, Calif.: Goodyear Publishing Co., 1969.

Hoos, Ida R. *Systems Analysis and Public Policy: A Critique.* Berkeley: University of California Press, 1972.

Kureckeberg, Donald, et al. *Urban Planning Analysis.* New York: John Wiley and Sons, 1974.

La Patra, Jack W. *Applying the Systems Approach to Urban Development.* Stroudsburg, Pa.: Dowden, Hutchinson and Ross, 1973.

Milkman, Raymond, et al. *Alleviating Economic Distress.* Lexington, Mass.: D.C. Heath and Co., 1972.

Tenzer, A.J., et al. *Applying the Concepts of Program Budgeting to the New York City Police Department.* New York: Rank, 1969, pp. 35-53.

U.S., Congress, Joint Economic Committee, Subcommittee on Economy in Government. "The Planning-Programming-Budgeting System: Progress and Potentials." In *Program Budgeting and Benefit-Cost Analysis,* edited by H.H. Hinrichs and G.M. Taylor. Pacific Palisades, Calif.: Goodyear Publishing Co., 1969.

Critical Path Method

PREREQUISITE TOOLS

None.

USAGE

PURPOSE

The Critical Path Method (CPM) is a networking technique for planning and managing projects.

USES

CPM aids in planning and managing the execution of activities in a project where the activities must be performed in a specified sequence. CPM:

1) Identifies critical activities which require special attention from management.

2) Assists in estimating the minimum total time needed to complete the project.

3) Gives the times when activities must be scheduled to complete the project in the minimum time.

4) Serves as a planning and management device to communicate complex procedures to staff and funding sources.

5) Facilitates the construction of Gantt Charts (GNT, page 252).

KEY DEFINITIONS

1) An *activity* is an operation with a well defined beginning and end, and a specific purpose. Some examples are PREPARE QUESTIONNAIRE and MAIL QUESTIONNAIRE, activities which may be necessary to complete a Survey (SVY, page 36).

2) A *critical activity* is an activity which, if not completed on time, will delay the entire project.

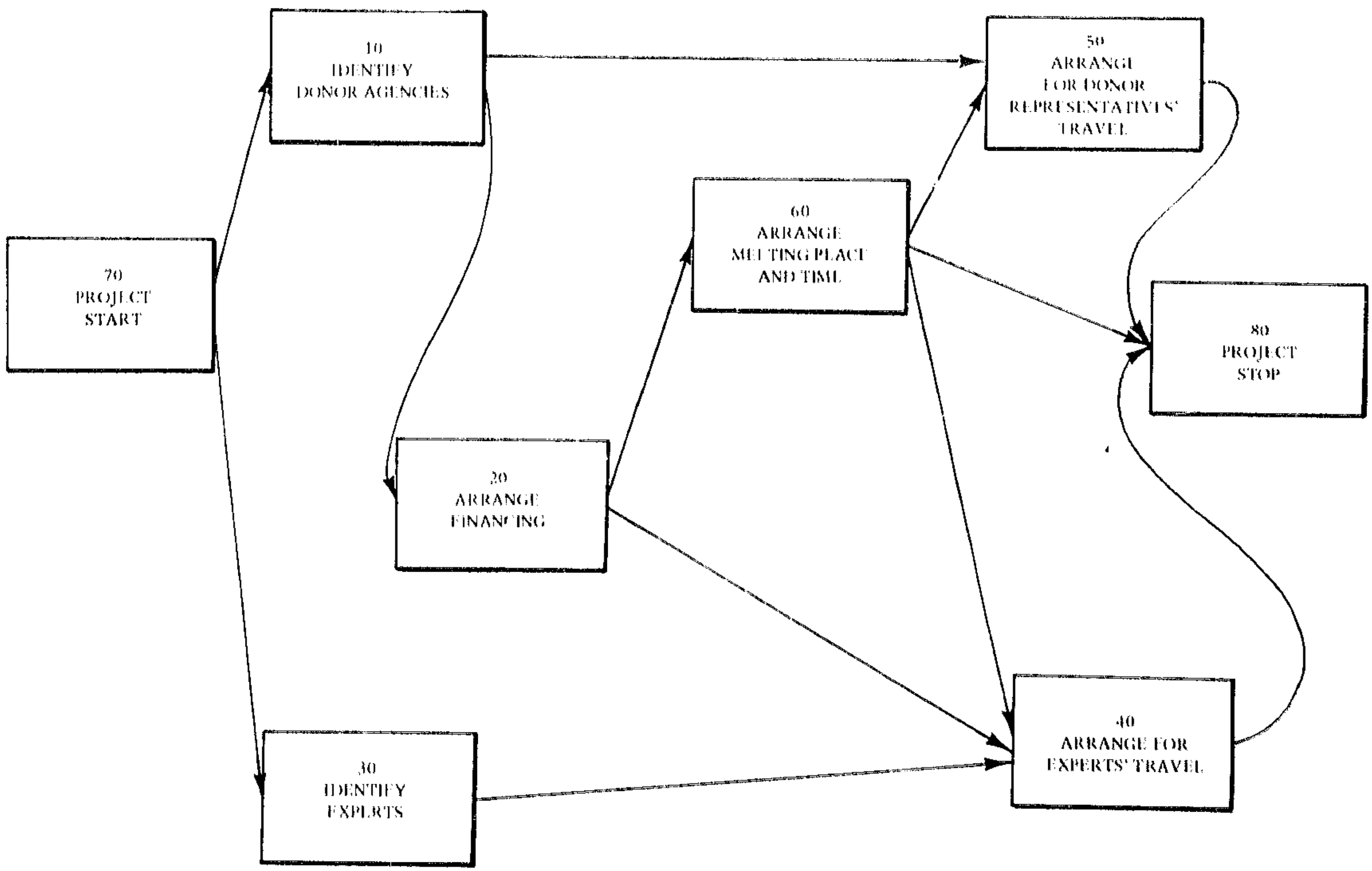
3) The *critical path* is the sequence of critical activities from project start to project finish that determine the shortest project duration.

SHORT DESCRIPTION

The Critical Path Method begins by describing the activities necessary to complete the project. The time required to complete each activity is estimated, taking into consideration the resources available and the desired performance specifications. Arranging the activities in a network shows the logical sequence from start to finish (see figure 1). The *critical path* through the network is computed by determining the activities which are critical to the timely completion of the project. From these calculations, the total time needed to complete the project may be estimated.

The Critical Path Method can be used during the management of the project to direct attention and resources to critical performance areas.

FIGURE 1
Project Network for the Activities Necessary to Arrange a Seminar



ADVANTAGES

1) Using CPM for a project promotes advance planning.

2) CPM provides a concise framework for an ongoing review of project progress.

3) The visual representation of the total project communicates effectively to line personnel, funding agencies, and other interest groups.

4) CPM identifies those activities that must be completed on time in order to end the project as early as possible. Extra attention can be devoted to these critical activities, or resources can be scheduled accordingly.

5) Using CPM frequently results in a significant reduction in project duration by avoiding unnecessary delays (Moder and Phillips, 1964).

LIMITATIONS

1) It is necessary to estimate in advance the exact nature and timing of each activity in the project.

2) The fact that most activities may take less time if resources are shifted from other activities is not treated in the critical path calculations.

3) CPM does not consider additional information that the project manager may have, e.g., the relative skill of different workers or the expected delay in procuring some resources.

4) It is tedious to manually analyze a CPM network containing more than 50 activities.

5) CPM does not consider planning projects when there is limited availability of a particular resource. Gantt Charts (GNT, page 252) may be used in such cases.

REQUIRED RESOURCES

LEVEL OF EFFORT

Drafting a CPM network for a large project can be a significant undertaking. However, when activities are identified during the planning or budgeting stage of the project, the CPM network may actually provide a framework which will reduce the total planning effort.

It may be necessary to update the network during the course of a project. This may be done on a weekly or monthly basis depending on the nature of the project.

SKILL LEVEL

The calculations on a simple network involve no more than simple arithmetic. For larger networks, the calculations are no more complex, but careful bookkeeping is important.

TIME REQUIRED

The time required depends on the number of activities, the decision maker's familiarity with the project, and the difficulty in getting accurate data estimates. Construction of the CPM network, analysis of critical activities, and computation of minimum total project time require one day for projects with less than 50 activities.

SPECIAL REQUIREMENTS

One index card (or something similar) for each activity is needed. Large sheets of paper may be needed to construct the CPM network for a large project. A calculator will be useful for chart computations. A computer is desirable for handling large project networks. Many CPM computer programs are available (see Moder and Phillips, 1964).

DESCRIPTION OF TOOL

SUPPLEMENTAL DEFINITIONS

1) The *duration* of an activity is the estimated time needed to perform the activity.

2) The *predecessor activity* for an activity must be completed before the latter can start.

3) An *immediate predecessor* of an activity is any other activity that immediately precedes it and which must be completed before the activity can start.

4) The *earliest start* (ES) of an activity is the earliest time (measured from the start of the project) when an activity may begin, assuming that all immediate predecessors are completed.

5) The *earliest finish* (EF) of an activity is the sum of its earliest start time and duration.

6) An *immediate successor* of an activity is any activity that immediately follows it and which may not start until completion of the activity.

7) The *latest finish* (LF) of an activity is the latest time (measured from the start of the project) when an activity may be completed without delaying any immediate successor(s), thereby delaying completion of the project.

8) The *latest start* (LS) of an activity is its latest finish time minus its duration.

9) *Slack* is the amount of leeway allowed in either starting or completing an activity. Slack can be computed in two ways:

$$\text{Slack} = LS - ES \quad [1]$$

$$\text{Slack} = LF - EF \quad [2]$$

which is simply the differences between the latest and earliest starts [1] or finishes [2].

10) A *milestone* is a point in time (specific date) which marks the completion of a sequence of activities or the beginning date for subsequent activities.

REQUIRED INPUTS

The Critical Path Method requires knowledge of the project objectives, and the activities necessary to achieve them, in order to estimate the duration of the different activities and construct the sequence.

TOOL OUTPUT

The CPM gives the minimum total project duration based on the identification of the critical path. The critical path calculations determine the leeway in scheduling each activity: the time interval designated by the earliest and latest start times and the earliest and latest finish times. This information enables the project manager to determine scheduling priorities and concentrate efforts on the critical activities, those activities which have no scheduling leeway or slack.

The CPM is the first step in preparing a Gantt Chart (GNT, page 252) for examination of any potential problems in allocating resources to the project.

IMPORTANT ASSUMPTIONS

All activities necessary to complete the project are known during the planning phase. All activities identified as necessary must be completed, i.e., there is no provision for alternative choices of action contingent upon later information or actions beyond the control of project planners. One may prepare alternative networks for each contingency (see Contingency Analysis, CGA, page 147).

The time estimates for each activity are determinate, i.e., CPM does not permit variation in estimating duration. The durations estimated for each activity are assumed to be independent of the other activity durations. Resources required to complete any activity are not constrained (see Davis, 1966).

METHOD OF USE

GENERAL PROCEDURE

Describing network techniques may be complicated, depending on the level of abstraction. This procedure is an easy approach for relatively simple networks: the analysis proceeds directly on the network. Other procedures which use a complex notation to represent the activities are not necessary unless the procedure is to be carried out on a computer.

1. Identify and list all activities necessary to complete the project.

1.1 Briefly describe each activity in the center of an index card (see figure 2).

1.2 Examine the activities and discard or modify any which are too detailed when compared with the other activities.

1.3 Give each activity an identifying number, e.g., 10, 20, 30, etc., leaving intervening numbers for activities which may be included later.

2. Estimate the duration of each activity.

2.1 Consider the normal level of resources available to complete the activity.

2.2 Consider the desired specifications for the activity's performance.

2.3 Write the duration at the bottom of each activity card (see figure 2).

2.4 List the activities and their durations (figure 3).

3. Draw the project network.

3.1 Place the activity cards on a large sheet of paper.

3.2 Arrange the activities in their logical sequence from left to right, and fasten the cards to the paper.

3.3 Use arrows to connect each activity to its immediate predecessors and immediate successors (see figure 4).

FIGURE 2
Activity Card with Location of Notations

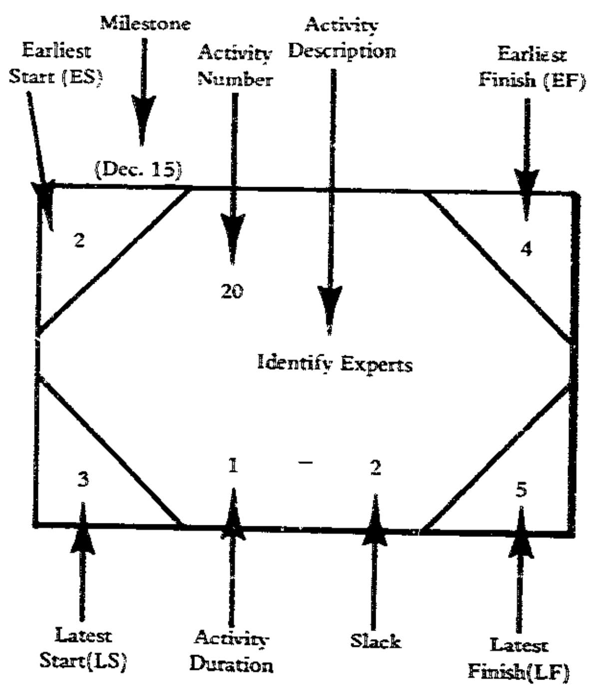
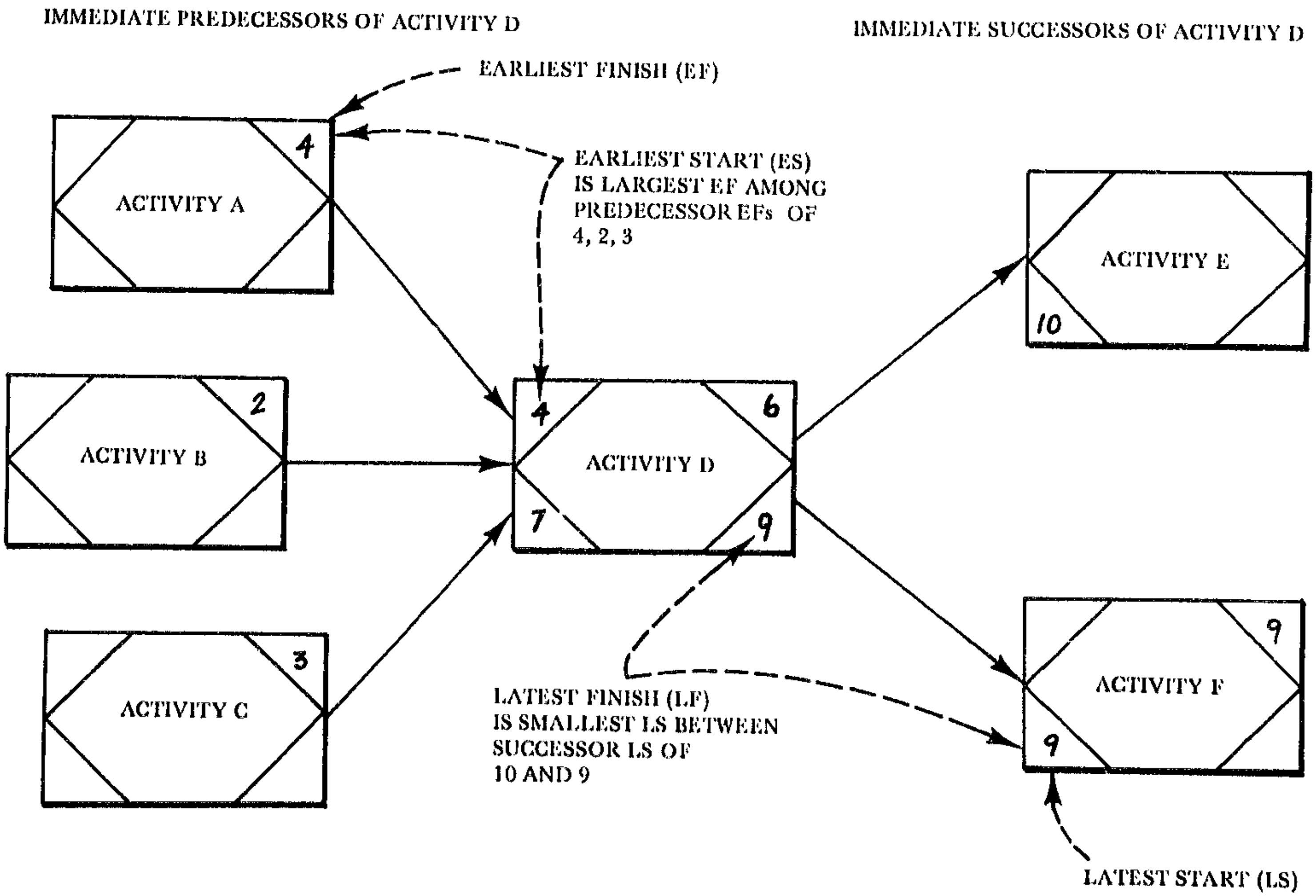


FIGURE 3
Table Format for Computation of Critical Path

PROJECT: NETWORK PLANNER: START DATE: TIME UNITS:

ACTIVITY		DURATION	IMMEDIATE PREDECESSORS	IMMEDIATE SUCCESSORS	START		FINISH		SLACK	STATUS
No.	Description				EARLIEST	LATEST	EARLIEST	LATEST		

FIGURE 4
Immediate Predecessor and Successor Relationships
and the Computation of Earliest Start and Latest Finish Times for an Activity



3.4 Check the network for the logical consistency of activity sequences.

3.5 Enter each activity's immediate predecessors and successors in the table (figure 3) using their identifying numbers.

4. **Identify the PROJECT START and the PROJECT STOP.**

4.1 If the project begins with several simultaneous activities (each having no immediate predecessors), then place a PROJECT START card on the network and connect it with arrows to these activities (see figure 1). This activity has zero duration.

4.2 If the project ends with several simultaneous activities (each having no immediate successors), then place a PROJECT STOP card on the network and connect it with arrows to these activities. This activity has zero duration.

4.3 Assign a reference time of zero to the desired starting date of the project.

5. **Determine each activity's earliest start (ES) and earliest finish (EF).**

5.1 Begin with PROJECT START and work forward through the network.

5.2 Set the ES for the PROJECT START equal to zero.

5.3 Compute the EF for each activity by adding the duration to its ES.

5.4 For each sequential activity with only one immediate predecessor, set the ES equal to the predecessor's EF.

5.5 For each sequential activity with more than one immediate predecessor, set the ES equal to the latest EF of the predecessor activities. The ES of an activity is the earliest time (measured from the start of the project) that an activity may begin assuming that all immediate predecessors are first completed. Therefore, the ES can be no earlier than the EF among the preceding activities (see figure 4). For example, if activity D is preceded by activities A, B, and C, and if the earliest that these activities may be finished is 4, 2, and 3 weeks from project start, respectively, then the earliest that activity D may start is the fourth week of the project, i.e., ES = 4.

5.6 Write the ES and EF on the top corners of the activity card (see figure 2) and enter in the table (figure 3).

5.7 Repeat steps 5.3 through 5.6 until the PROJECT STOP is reached. Note, the ES for an activity may be calculated only after the EFs of all immediate predecessors have been determined.

6. **Determine each activity's latest start (LS) and latest finish (LF).**

6.1 Begin at the PROJECT STOP and work backward through the network.

6.2 Set the LF for the PROJECT STOP equal to its EF.

6.3 Compute the LS for each activity by subtracting the duration from its LF.

6.4 For each activity with only one immediate successor, set LF equal to the LS of the successor activity.

6.5 For each activity with more than one immediate successor, set the LF equal to the earliest LS of the successor activities. The LF of an activity is the latest time (measured from the start of the project) when an activity may be completed without delaying the project. Consequently, the LF must be no later than the LS times for all the activity's immediate successors (see figure 4). For example, if activity D is immediately followed by activities E and F and if the latest that these activities may begin is 10 and 9 weeks, respectively, then the latest that activity D may finish is the ninth week of the project, i.e., LF = 9.

6.6 Write the LS and LF on the bottom corners of the activity card (see figure 2) and enter in the table (figure 3).

6.7 Repeat steps 6.3 through 6.7 until the PROJECT START is reached. Note the LF for an activity may be calculated only after the LSs of all immediate successors have been determined; hence the necessity to pass backward through the network.

7. **Compute the slack times for each activity.**

7.1 Slack is zero for an activity with identical ES and LS or identical EF and LF.

7.2 Otherwise, slack is simply the difference in time between the ES and LS or between the EF and LF of each activity.

7.3 Write the slack at the bottom of each activity card (see figure 2) and enter it in the table.

7.4 Check the calculations for each activity by adding the duration and slack to the earliest start time. The sum should give the latest finish time for the activity.

8. **Identify the critical path for the project.**

8.1 Any activity with zero slack is critical. Mark the status in the table (figure 3).

8.2 The sequence of critical activities from start to finish is the critical path for the project. (There may be more than one critical path.) Mark the critical path on the network diagram with heavy lines on the connecting arrows and/or by shading the critical activity cards in the sequence.

9. Determine the duration of the project.

9.1 Examine the sequence of activities to see if all activities are necessary, or if the project method might be changed (Mulvaney, 1969).

9.2 Examine the activities on the critical path to see if they might be shortened in duration.

9.3 Consider the application of additional resources to shorten critical activities.

9.4 Consider a change in specified performance of the activity to shorten the estimated duration.

9.5 Finally, take the duration of the project as the EF of the final activity or PROJECT STOP.

10. Use the project network to manage the project.

10.1 Assuming the project is to be completed as early as possible, set the calendar date of the PROJECT START at the earliest feasible time. This becomes the time reference for scheduling all subsequent activities.

10.2 Schedule every activity to start in its ES to LS time interval. Note that there will be no leeway in scheduling critical activities.

10.3 If days are the basic time unit, schedule according to calendar working days (unless overtime is authorized).

10.4 If a deadline for completion of the project has been set and if resources and staff are not available until the last minute, set the PROJECT START date by subtracting the total project time from the deadline.

10.5 Write in significant *milestones* on the network using the elapsed time from the date of the PROJECT START. Milestones usually mark the latest finish date for several simultaneous activity sequences.

EXAMPLE

Though the Critical Path Method is most useful for projects involving 50 or more activities, a simpler example illustrates the technique: a planning seminar which brings experts together with donor agency representatives.

Identify and List All Activities Necessary to Complete the Project

The seminar plan calls for selection of donors and experts and the arrangement of financing, facilities, and travel. These activities are listed in table form (see figure 5). All activities involve about the same level of detail, i.e., minute specification of tasks is omitted at this stage. Many other activities may be necessary to plan a particular seminar, but only six tasks are shown in order to simplify the example.

Estimate the Duration of Each Activity

The durations shown in figure 5 are in time units of weeks. These are estimates based on the number of experts and donor representatives involved in the seminar and the staff available to complete the activities.

Draw the Project Network

The activities are written on index cards and arranged in a logical sequence (see figure 1). Initially, the network may look rather confusing with many arrows criss-crossing. Sometimes rearranging the activity cards and redrawing connecting arrows will clarify the diagram. If crossing two arrows cannot be avoided, use a "bridge" for clarity.

Check the network for consistency. Is the activity sequence logical? Can activities sequenced one after the other be performed simultaneously? Activities 10 and 30 are illustrative.

The immediate predecessors and successors of all activities are noted in the table (see figure 5).

Identify the PROJECT START and the PROJECT STOP

In this example, it is necessary to add both a PROJECT START and a PROJECT STOP activity as the project begins and ends with simultaneous activities. The final activity is not HOLD THE SEMINAR since the project is completed when arrangements for the seminar are finished. This includes setting a date (which may be in several months).

Determine Each Activity's Earliest Start and Earliest Finish

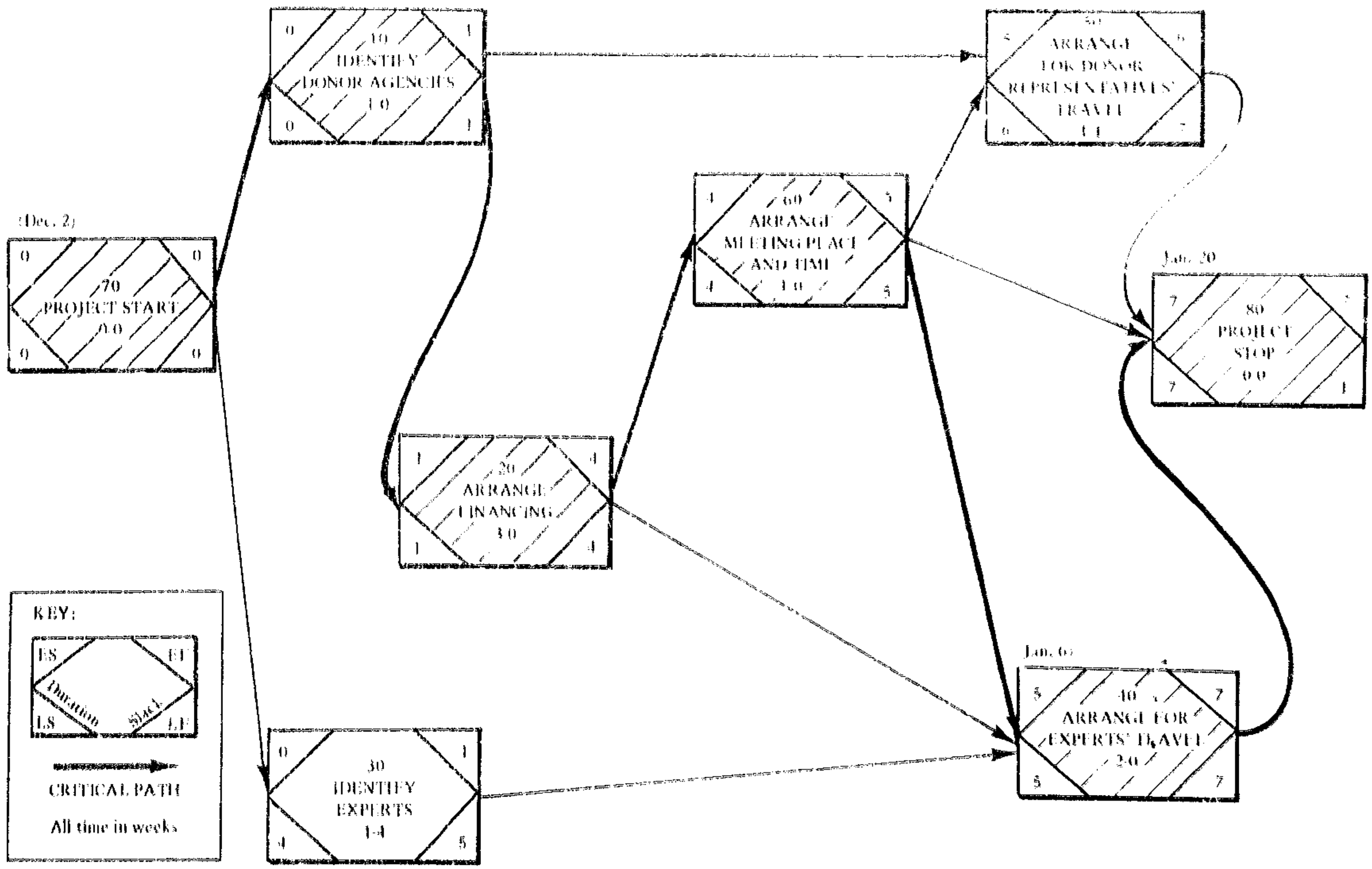
Computation of the earliest start and finish is shown directly on the top corners of each activity card (see figure 6). For example, activity 50, ARRANGE FOR DONOR REPRESENTATIVE'S TRAVEL, is preceded by activities 10 and 60 which have earliest finish times of one and five weeks, respectively. Since activity 50 may start only after all preceding activities are finished, its ES is five weeks from the starting date of the project.

FIGURE 5
Completed Activity Table for Activities to Arrange a Seminar

PROJECT: Arrange Donor Sponsored Seminar NETWORK PLANNER: D. Susskind START DATE: Dec. 2 TIME UNITS: Weeks

No.	ACTIVITY	DURATION	IMMEDIATE PREDECESSORS	IMMEDIATE SUCCESSORS	START EARLIEST	START LATEST	FINISH EARLIEST	FINISH LATEST	SLACK	STATUS
10	Identify Donor Agencies	1	70	20, 50	0	0	1	1	0	CRITICAL
20	Arrange Financing	3	10	40, 60	1	1	4	4	0	CRITICAL
30	Identify Experts	1	70	40	0	4	1	5	4	
40	Arrange for Experts' Travel	2	20, 30, 60	80	5	5	7	7	0	CRITICAL
50	Arrange for Donor Representatives' Travel	1	10, 60	80	5	6	6	7	1	
60	Arrange Meeting Place and Time	1	20	40, 50, 80	4	4	5	5	0	CRITICAL
70	PROJECT START	0		10, 30	0	0	0	0	0	
80	PROJECT STOP	0	40, 50, 60		7	7	7	7	0	

FIGURE 6
Completed Project Network Showing Critical Path (Shaded) and Milestones (Dates in Parentheses)



Determine Each Activity's Latest Start and Latest Finish

These times are computed directly by working back through the network (see figure 6). For example, activity 60, ARRANGE MEETING TIME AND PLACE, has three immediate successors, activities 40, 50, and 80 (the PROJECT STOP). These activities have latest starts of five, six, and seven weeks, respectively, from the starting date of the project. Since activity 60 must finish before the following activities can begin, the latest finish is five weeks from the PROJECT START.

The latest start time of the PROJECT START is computed as zero. This provides an easy check of the computations for all activities.

Compute the Slack Times for Each Activity

The slack for each activity is shown on the activity card and in the table (figure 5). Activity 30 has the largest slack—four weeks. Since its ES is week zero and its LF is week five, experts may be identified during any week in this time period. This task has been estimated to take only a week, but it would be wise to schedule it as early as possible (even though there are four weeks of slack).

Identify the Critical Path for the Project

The activities with zero slack are noted in the table (figure 5) by writing "critical" under the status column. The critical path is shown on the network by shading the critical activity cards and darkening the connecting arrows (see figure 6).

Determine the Duration of the Project

The earliest finish of the last activity is seven weeks from the PROJECT START date. Upon examining the critical path, one may conclude that the most likely place to shorten the time is to expedite the arrangements for financing. However, since this is largely beyond the planner's control, the total estimated completion time is seven weeks, the EF for the PROJECT STOP.

Use the Network to Manage the Project

The starting time for the project is to be December 2. When the activities with slack are scheduled, the planning is finished (note that the table, figure 5, is not a schedule). The beginning of activity 40 is selected as a key event in the project and the milestone date of January 6 is shown directly on the network diagram (see figure 6). The project manager assigns staff roles to each task and monitors progress against the planned performance. Construction of a Gantt Chart (GNT, page 252) facilitates these tasks.

This example could be expanded to reflect the many details that go into setting up a seminar and activities prior to the date of the conference may be appended to the network to give the total picture. However, it is usually good practice to start with a network that identifies the gross activities and then to redo the network with a finer breakdown.

THEORY

The Critical Path Method (CPM) and Project Evaluation and Review Technique (PERT) were both developed in the late 1950s (Moder and Phillips, 1964). Originally, the CPM network technique considered the costs of shortening critical activities and thus optimized the timing of the task. PERT permitted three time estimates (pessimistic, optimistic, and most likely) for the duration of each activity. PERT allowed the planners to estimate a date for project completion, including his confidence in the variance of the estimate (Bedworth, 1973).

Subsequently, these two techniques have been expanded and modified, and many other network techniques have been developed. Davis (1966) gave an excellent survey of the treatment of resource allocation in networks. Pritsker and Happ (1966) developed a method which considered the probability of certain activities not occurring (a limiting assumption of CPM).

From the beginning, network techniques have been programmed for digital computers. Moder and Phillips (1964) listed some of the many versions. Efforts to simplify the technique for manual computation draw from the desirable features of both PERT and CPM as well as Gantt or Bar Charts. Mulvaney (1969) gave an excellent treatment which serves as the model for this tool description.

BIBLIOGRAPHY

Bedworth, David B. *Industrial Systems, Planning, Analysis, Control.* New York: The Ronald Press Co., 1973.

Davis, Edward W. "Resource Allocation in Project Network Models: A Survey." *The Journal of Industrial Engineering* 17 (March-April, 1966): 177-88.

Moder, J.J., and Phillips, C.R. *Project Management with CPM and PERT.* New York: Rheinhold Publishing, 1964.

Mulvaney, John. *Analysis Bar Charting: A Simplified Critical Path Analysis Technique.* Washington, D.C.: World Bank, Economic Development Institute, 1969.

Pritsker, A.A., and Happ, W.W. "GERT: Graphical Evaluation and Review Technique, Part I, Fundamentals." *Journal of Industrial Engineering* 17 (May, 1966).

Gantt Charts

PREREQUISITE TOOLS

Critical Path Method (CPM, page 241).

USAGE

PURPOSE

The Gantt Chart facilitates planning and managing project activities and resources.

USES

The Gantt Chart is used to:

1) Plan a project to schedule *activities.*

2) Communicate the project plan to others and to mark *milestones* in the project sequence.

3) Determine the minimum project duration, given that some *resources* may be limited.

Project managers may use Gantt Charts to schedule resources and staff assignments and to record actual progress against the planned performance of activities.

SHORT DESCRIPTION

A Gantt Chart displays the schedule of project activities (see figure 1). Each activity is represented by a bar that extends along the time scale. The bar's length is proportional to the *duration* of the activity. The position of the bar along the time scale indicates the starting and ending times for the activity.

The required amount of a limited resource (e.g., manpower) may be tabulated for each unit of time to allow for a direct examination of scheduling problems. Activities may be shifted to keep the total amount of the resource within the limit.

ADVANTAGES

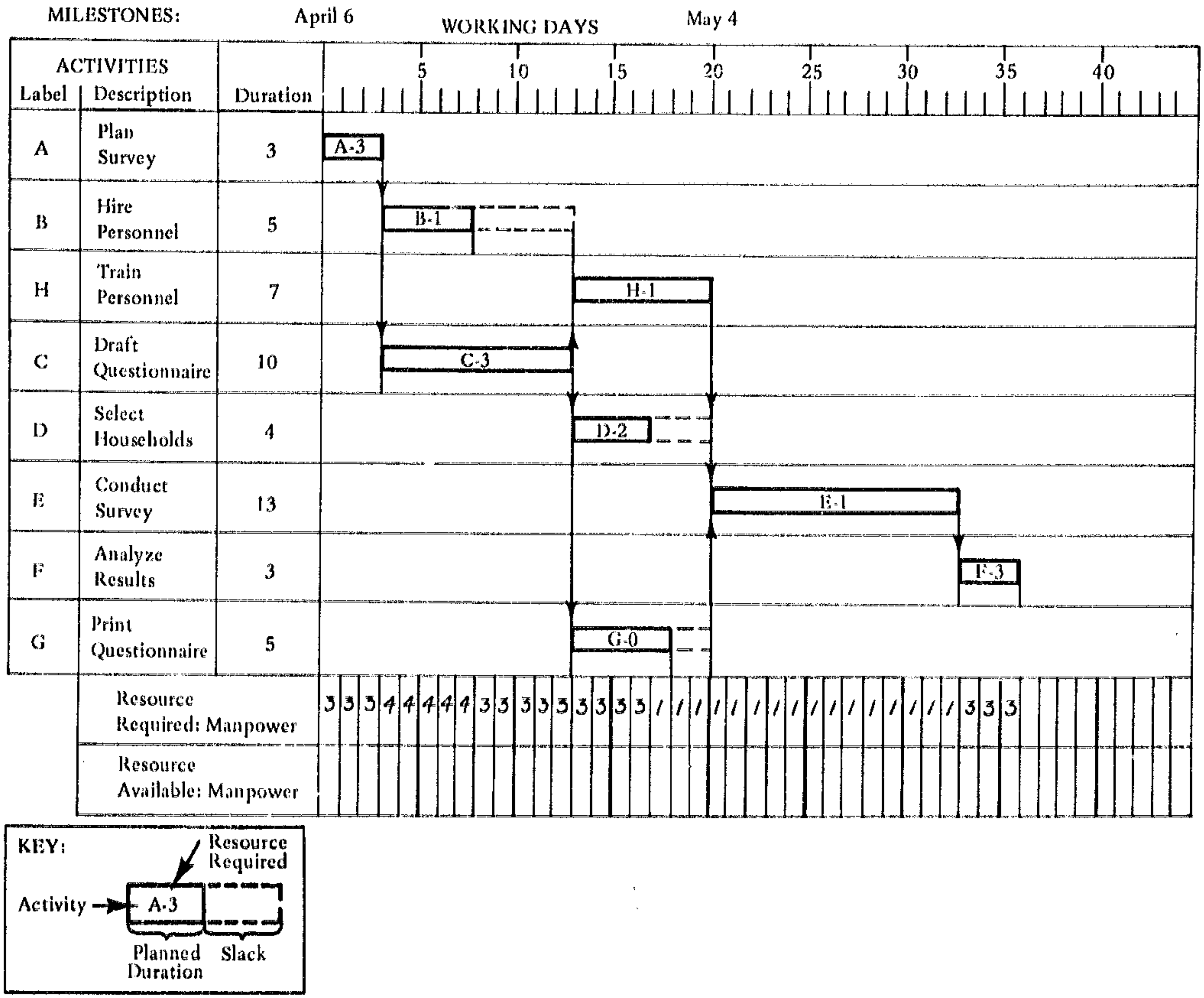
The primary advantage of the Gantt Chart is its simplicity and intuitive appeal. It is a popular scheduling device because the timing of each task is clearly indicated.

The *critical path* or sequence of *critical activities* is revealed on a Gantt Chart by direct inspection; there will be no leeway in scheduling these activities if the project is to be completed in a minimum time.

Allocation of a limited resource can be explicitly treated on the chart, and activities can be rescheduled or resources shifted from one activity to another.

Milestones may be marked to clearly show important intermediate stages of the project. The project's progress may be marked directly on the Gantt Chart; if preceding activities are not completed at the corresponding milestone, then corrective action is indicated. For example, the 20th working day after project start is a milestone for a survey project (see figure 1).

FIGURE 1
A Gantt Chart Example: Planning and Conducting a Survey



LIMITATIONS

The Gantt Chart does not emphasize the logical sequence of activities as clearly as the network diagrams in the Critical Path Method (CPM, page 241).

If more than one resource is limited, the Gantt Chart technique does not ensure an optimum resource allocation.

REQUIRED RESOURCES

SKILL LEVEL

As in any project planning technique, developing a Gantt Chart requires breaking down a project into its logical and distinct activities. It also requires estimating the duration of activities and resource requirements. Since there is a tradeoff between resources allocated and the duration of an activity, these tasks are enhanced by repeated practice in constructing charts and comparing estimates with actual progress.

TIME REQUIRED

The time required is directly related to the complexity of the project to be scheduled. Experience in estimating resource requirements and task duration shortens chart construction time. Gantt Charts often require updating during project implementation.

DESCRIPTION OF TOOL

REQUIRED INPUTS

Knowledge of the activities necessary to complete a project is the precondition for developing a Gantt Chart. The dates for starting and ending the project fix the time scale of the Gantt Chart. Resource needs and availability must be specified.

TOOL OUTPUT

The primary output is a project schedule depicted by a Gantt Chart. The Chart can then be used to mark the progress of the project and to adjust it according to management decisions.

IMPORTANT ASSUMPTIONS

The Gantt Chart construction assumes that a project may be broken down into clearly distinguishable activities with a definite beginning and end: that is, the time to complete each activity can be accurately determined during the planning phase.

The Gantt Chart technique does not enable optimum allocation of resources—more sophisticated techniques are required (Davis, 1966). However, the technique is useful for graphically sequencing activities to avoid exceeding the amount of a limited key resource. This assumes that the interaction between required resources and the duration of an activity can be specified (e.g., if additional manpower is assigned to the activity, is the duration shortened). Determination of the minimum project duration using a Gantt Chart is depending on these relationships (see Bedworth, 1973).

METHOD OF USE

GENERAL PROCEDURE

A Gantt or Bar Chart is constructed by identifying all the activities involved in the project and determining their sequences. Each activity is drawn as a bar located on a time scale so that the length of the bar corresponds to the duration of the activity and the position of the bar denotes its scheduled start and end (see figure 1).

The following procedure concentrates on constructing a Gantt Chart as a heuristic technique for taking into account the requirements for a limited resource. As such, it extends the Critical Path Method (CPM, page 241).

1. **Construct the CPM network for the project.**
   - 1.1 Diagram the network in order to observe the logical sequence of project activities.
   - 1.2 Compute the earliest (ES) and latest starts (LS) for each activity and the earliest (EF) and the latest finishes (LF) for each activity.
   - 1.3 Compute the slack for each activity and determine the critical path.
   - 1.4 Estimate the minimum project duration.
   - 1.5 Estimate how much of the limited resource is necessary for each activity.

2. **Construct the Gantt Chart for an unlimited resource.**
   - 2.1 Mark off a horizontal time scale approximately one-third greater than the estimated minimum project duration. (If the time unit is in days, then include only working days unless overtime is considered.)
   - 2.2 Draw a horizontal bar for the first activity lying on the critical path by starting at the zero reference on the time scale and extending to the estimated duration of the activity.

2.3 Draw a bar on the chart which corresponds to the duration of the next activity on the critical path. The beginning of the bar must fall on the same vertical time line as the finish of the preceding activity. The bars may be drawn in the same row of the chart or in different rows to facilitate identification of the activity (see figure 1).

2.4 Continue adding bars consecutively until all the critical activities in the path are represented on the chart.

2.5 Make certain that the end of the bar for the last activity falls on a vertical line on the time scale which equals the estimated minimum project duration.

2.6 Add the activities not on a critical path to the chart. The position of the bar is determined by the earliest start and earliest finish times of the project activity.

2.7 Append a bar to the right end of each non-critical activity. The length should equal the slack for the activity (see CPM, page 241).

2.8 Draw vertical arrows between the ends of the bars to show the *predecessor activities* for each activity (see figure 1).

3. Determine resource requirements.

3.1 Write the amount of the limited resource required for each activity directly on the bar.

3.2 Starting with the first time unit on the scale (e.g., day 1 or week 1), add the amount of the limited resource used in all activities scheduled at that time and enter it in the column below the chart (see figure 1).

3.3 Continue calculating the total resources required for the rest of the time units.

3.4 Sum these unit totals to give the total resource requirement for the project.

3.5 Divide this total by the number of time units to give the average resource requirement per unit of time (e.g., man per day, secretaries per week, computer hours per month). This gives an indication of how uniformly the limited resource is used by the scheduled activities.

4. Adjust the schedule for the limited resource.

4.1 Record the amount of the limited resource which is available for each time unit of the project (see figure 1).

4.2 Compare this to the total resource requirement estimated for each time unit.

4.3 If the amount of resource required exceeds the amount available, then the schedule for that time unit must be shifted.

4.4 Within the constraints posed by the logical sequence of activities, shift activities forward or backward along the time scale so that the total resources required do not exceed those available.

4.5 Consider lengthening the duration of non-critical activities to reduce their resource requirement.

4.6 If necessary schedule two simultaneous activities to follow each other sequentially.

4.7 Extend the total project duration, if necessary, to avoid exceeding resource limitations.

4.8 Make certain after any modification of the original schedule that no activity has been shifted such that it starts before all predecessor activities are finished.

5. Use the Gantt Chart to manage the project.

5.1 Indicate the significant milestones by drawing a vertical line through the appropriate date.

5.2 Consider the scheduling of activities with slack: if the activity is scheduled for the earliest start time, the slack will all occur at the end; if the activity is scheduled to start at the latest possible time, the activity will become critical to avoid delays in subsequent activities (and the project).

5.3 Assign staff and other resources to each activity and discuss the schedule and expected performance.

5.4 Develop a reporting system which can be used to mark the progress and completion of each activity on the chart.

5.5 Provide for a periodic staff review of project activities to emphasize the interdependency of the work.

5.6 If the project fails to meet the schedule, update the chart and, if necessary, recalculate the critical path for the remaining activities. This process is facilitated by providing space on charts to add activities and to expand or shift the time scale.

EXAMPLE

A simple Gantt Chart illustrates the activities required to design and executive a survey (SVY, page 36). The example is adopted from Moder and Phillips (1964).

Construct the CPM Network for the Project

The survey task was broken down into eight activities, and the CPM network was constructed (see figure 2). The earliest and latest starts and finishes and the slack for each activity were calculated on the network and tabulated (see figure 3). The minimum duration for the project was estimated to be 36 days.

FIGURE 2
Critical Path Network for Survey Project

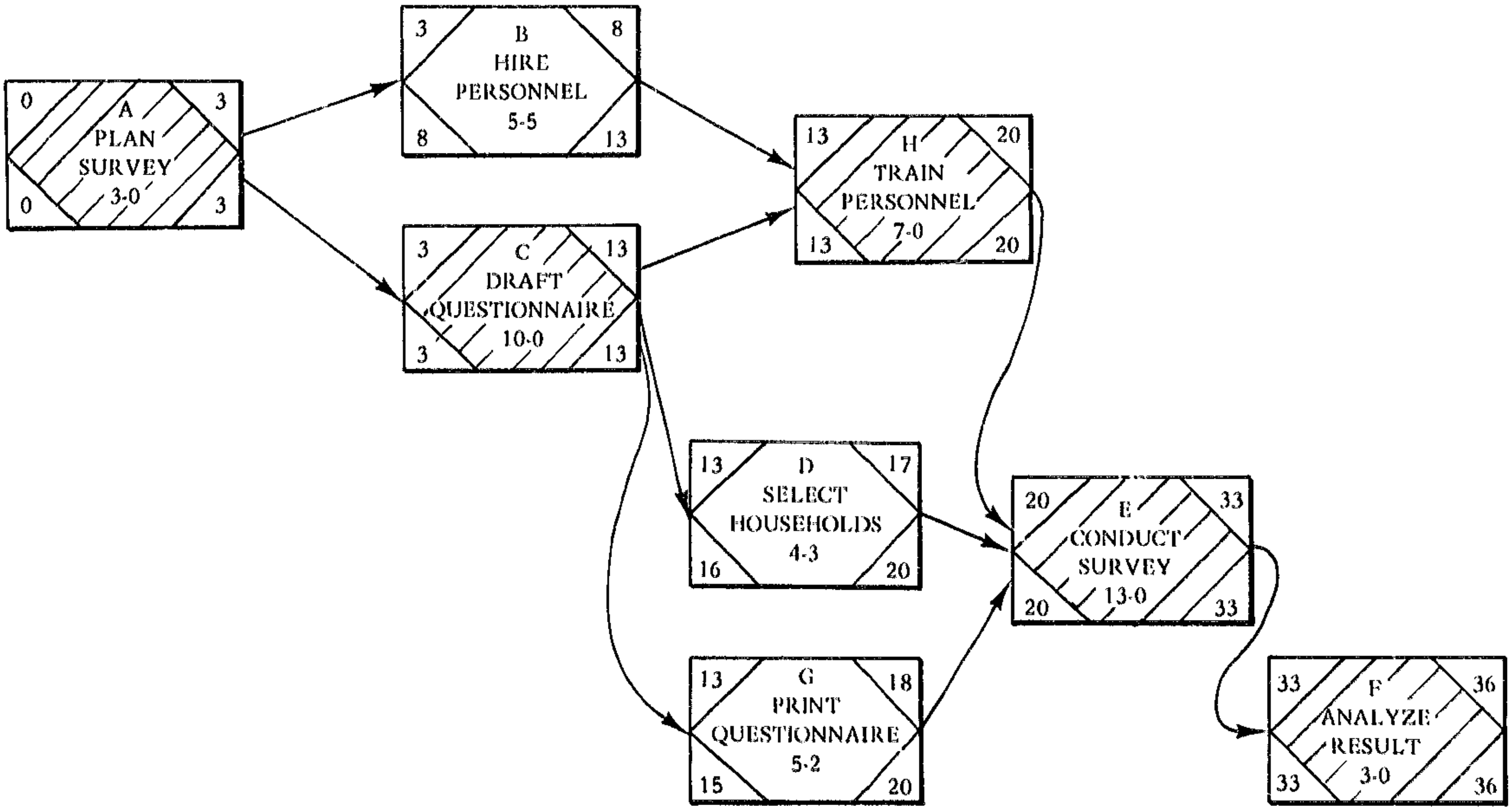


FIGURE 3
Activity Table for Survey Project

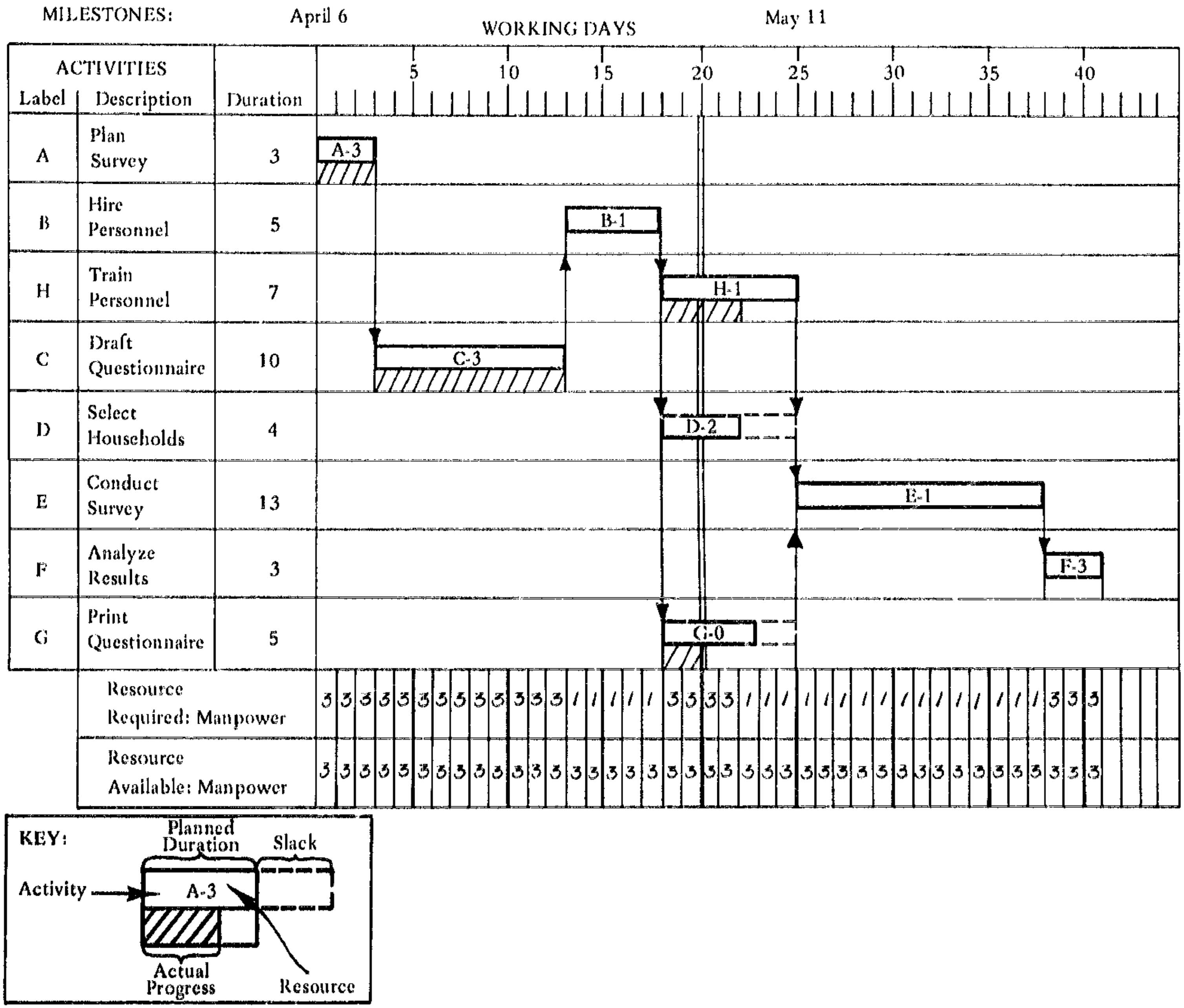
PROJECT: Planning and Conducting a Survey NETWORK PLANNER: G. Gallup START DATE: April 6 TIME UNITS: Days

ACTIVITY No.	ACTIVITY Description	DURATION	RESOURCE	IMMEDIATE PREDECESSORS	IMMEDIATE SUCCESSORS	START EARLIEST	START LATEST	FINISH EARLIEST	FINISH LATEST	SLACK	STATUS
A	PLAN SURVEY	3	3	--	B,C	0	0	3	3	0	Critical
B	HIRE PERSONNEL	5	1	A	H	3	8	8	13	5	
C	DRAFT QUESTIONNAIRE	10	3	A	D,G,H	3	3	13	13	0	Critical
D	SELECT HOUSEHOLDS	4	2	C	E	13	16	17	20	3	
E	CONDUCT SURVEY	13	1*	D,G,H	F	20	20	33	33	0	Critical
F	ANALYZE RESULT	3	3	E		33	33	36	36	0	Critical
G	PRINT QUESTIONNAIRE	5	0**	C	G	13	15	18	20	2	
H	TRAIN PERSONNEL	7	1	B,C	E	13	13	20	20	0	Critical

LIMITED RESOURCE: Manpower

*Only one supervisory staff required
**Sent to printers

FIGURE 4
Gantt Chart for Survey Example after Adjustments for Limited Manpower



The limited resource for this example was the staff available for planning and conducting the survey. The manpower necessary for each activity was determined (see figure 3, column 4).

Construct the Gantt Chart for an Unlimited Resource

The Gantt Chart is shown in figure 1. The scale is in working days. Note that the slack for non-critical activities is shown directly on the time scale. This chart represents an early start schedule since the slack period always follows each activity.

Determine Resource Requirements

The total resources for each day were tabulated. The total requirement for the project was 81 man-days; the average daily requirement was 2.44 men.

Adjust the Schedule for the Limited Resource

No more than three staff members are available during the project. Though this exceeded the average requirement, a comparison with the Gantt Chart (figure 1) revealed that four men are needed on days three through eight of the schedule. Hiring personnel to conduct the survey and designing and drafting the questionnaire could not be scheduled concurrently. All three staff members were needed to draft the questionnaire and the duration of that activity remained as estimated Five days of slack followed the hiring of personnel; this task's manpower requirement could be halved and the duration doubled without delaying the project. Yet, the resources required would still have exceeded those available by half a staff person per day. Assuming that the job of hiring personnel could not be delegated to another part of the organization, the only remaining choice was to reschedule the two activities so that they no longer overlapped.

The revised schedule required a minimum of 41 days, but the manpower requirement remained within the limits for the entire project period (see figure 4). The average daily staff requirement was just under two men. Activity B, HIRE PERSONNEL, became a critical activity in this schedule.

Use the Gantt Chart to Manage the Project

Milestones were added to the Gantt Chart at 25 working days, or May 11, assuming the project began on April 6. The non-critical activities were scheduled to start at their earliest feasible time in order to provide a cushion if time estimates were wrong or delays occurred. The progress as of May 4 (20 working days after the project began) was shown on the chart by cross-hatching the status of each activity. Note that household selection had not started, and attention was given to getting that task underway. However, it was not necessary to redraw the Gantt Chart since there was sufficient slack to complete this task without delaying the project.

THEORY

The construction of a Bar Chart to illustrate the schedule of project activities originates from management practice rather than from a complex theory. However, the Gantt Chart technique as described here draws from two theoretical areas: network scheduling techniques (see, for example, Moder and Phillips, 1964) and resource allocation theory (see Davis, 1966, for a review of relevant theory).

The Gantt Chart technique described in the general procedure section constructs a time-scaled CPM network: that is, a network in which the length of the connecting arrows shows the duration of the activities.

The Gantt Chart provides a graphic record-keeping format for scheduling a limited resource. It does not provide a means for optimum allocation of scarce resources as this is beyond a trial and error approach. The technique has been described as heuristic and, as such, is more an art than a science (see Mulvaney, 1969, and Bedworth, 1973).

BIBLIOGRAPHY

Bedworth, David B. *Industrial Systems, Planning, Analysis, Control.* New York: The Ronald Press Co., 1973.

Davis, Edward W. "Resource Allocation in Project Network Models: A Survey." *The Journal of Industrial Engineering* 17 (March-April, 1966): 177-88.

Moder, J.J., and Phillips, C.R. *Project Management with CPM and PERT.* New York: Rhienhold Publishing, 1964.

Mulvaney, John. *Analysis-Bar Charting: A Simplified Critical Path Analysis Technique.* Washington, D.C.: World Bank, Economic Development Institute, 1969.

Pritsker, A.A., and Happ, W.W. "GERT: Graphical Evaluation and Review Technique, Part 1, Fundamentals." *Journal of Industrial Engineering* 17 (May, 1966).

Logical Framework

PREREQUISITE TOOLS

None.

USAGE

PURPOSE

Logical Framework enables the decision maker to identify project purposes and goals and plan for project outputs and inputs.

USES

The Logical Framework has been used widely by USAID Missions to:

1) Aid in planning a project.
2) Provide measures to evaluate a project.
3) State assumptions about causal linkages.

KEY DEFINITIONS

1) The *purpose* of a project is its primary intention or aim; it is the reason why a project is designed.

2) The *goal* of a project is a value judgment which satisfies one or more human needs. A *program* or *sector* goal is the broader objective to which a project contributes.

3) The *outputs* of a project are the desired and undesired results of the transformation process of a system, e.g., patients leaving a hospital, cured or not, are the results of a health delivery system.

4) The *inputs* of a project are the people, information, and/or physical items which enter the system to be transformed by a sequence into the outputs of the system, e.g., for an agricultural development project, inputs may be seeds, money, etc.

5) The *sector* is the larger system of which a project is part, e.g., building a dam is a project in the agricultural sector.

6) *Objectively verifiable indicators* demonstrate that certain desired results are being accomplished.

7) *Means of verification* are the specific mechanisms by which quantitative indications of the accomplishment of a project may be observed.

SHORT DESCRIPTION

The decision maker uses two types of logic to arrive at explicit statements which serve to help in planning or in evaluating a project in progress.

A vertical logic clarifies why a project is being undertaken. It specifies the program or *sector goal*, and project *purposes, outputs*, and *inputs*.

A horizontal logic identifies what is to be produced and the evidence that will signal success. It lists *objectively verifiable indicators, means of verification*, and important assumptions. Figure 1 presents the basic format for the Logical Framework.

FIGURE 1
The "Logical Framework"

PROJECT DESIGN SUMMARY
LOGICAL FRAMEWORK

Project Title: ______________

Life of Project:
From FY ______ to FY ______
Total U.S. Funding ______
Date Prepared: ______

NARRATIVE SUMMARY	OBJECTIVELY VERIFIABLE	MEANS OF VERIFICATION	IMPORTANT ASSUMPTIONS
Program or Sector Goal: The broader objective to which this project contributes	Measures of Goal Achievement:		Assumptions for achieving goal targets:
Project Purpose:	Conditions that will indicate purpose has been achieved: End of project status.		Assumptions for achieving purpose:
Outputs:	Magnitude of Outputs:		Assumptions for providing outputs:
Inputs:	Implementation Target (Type and Quantity)		Assumptions for providing inputs:

SOURCE: Reprinted from Leon J. Rosenberg and Molly Hageboeck, "Management Technology and the Developing World," in *System Approaches to Developing Countries*, Proceedings of the symposium sponsored by IFAC and IFORS, May 28-31, 1973. Algiers, Algeria, page 5. Used with permission.

ADVANTAGES

1) The Logical Framework is simple to understand. It provides a structure for concepts, ensuring that the decision maker thinks through the fundamental aspects of a project design.

2) The framework aids in evaluating a project since both initial goals and final results are clearly delineated (similar to the System Definition Matrix, SDM, page 67). By explicitly identifying how the project is to be evaluated, the decision maker can make realistic estimates of project outcomes and can identify problems which might be encountered.

LIMITATIONS

1) During the planning process, the Logical Framework does not take uncertainty into account. Neither does it allow for the consideration of potential alternative actions.

2) A linear causal sequence is assumed which is an unlikely simplification of the relationships among various project components and elements in the environment (see Oval Diagramming, OVD, page 81).

REQUIRED RESOURCES

LEVEL OF EFFORT

The decision maker must define the project goals, purposes, inputs, and outputs in measurable or objectively verifiable terms. Thus, while the Logical Framework may guide the planning process, it is not a substitute for the considerable effort required to plan effectively.

SKILL LEVEL

The decision maker must be able to think logically and to consider the important attributes, both quantitative and qualitative, of the project.

TIME REQUIRED

Completing the Logical Framework takes from several days to several weeks, depending on the size of the project.

DESCRIPTION OF TOOL

REQUIRED INPUTS

The decision maker needs to identify the project which is part of a program or sector. The success of a program depends on the success of the various projects carried out within that program or sector.

Other tools may be used to complete the Logical Framework. The objective tree (OBT, page 49) can help to structure goals, purposes, and criteria for evaluation. To explore the links between inputs and outputs, interaction matrix diagrams (IMD, page 92) would be useful. To develop a more thorough structure of a system, the System Definition Matrix (SDM, page 67) can be used.

TOOL OUTPUT

The completed Logical Framework matrix is one output of the technique. The other is the contribution that the process makes to the project design or evaluation. By thinking through the horizontal logic, crucial hypotheses about causal linkages may be determined. Developing the horizontal logic forces the planner to think in terms of realizable results. The Logical Framework then serves as a statement which, to some degree, indicates the completeness and soundness of these analytical processes.

IMPORTANT ASSUMPTIONS

Underlying any planning technique of this sort is an assumption of the inherent rationality of project interventions. One need only identify the causal linkages from inputs to outputs to purpose, and the project has been designed systematically. Yet it is not a systems design necessarily, since systems seldom exhibit exclusively linear causality. There are interactions with environmental components, feedback relationships, and complex relationships among the elements of the system. Thus the Logical Framework assumes a simplicity qualified only by entries in the "assumptions" column.

METHOD OF USE

GENERAL PROCEDURE

The recommended procedure is based on the work of Rosenberg and Hageboeck (1973) and the Office of Program Evaluation, USAID (1974). The vertical logic (column 1 in figure 1) clarifies why a project is being undertaken. It characterizes a project as a set of linked hypotheses:

If we provide the following inputs,
  then we can produce the requisite outputs.
If we produce those outputs,
  then the purpose will be achieved.
If the purpose is achieved,
  then the goal will be realized.*

*Leon J. Rosenberg and Molly Hageboeck, "Management Technology and the Developing World," in *Systems Approaches to Developing Countries,* Proceedings of the Symposium sponsored by IFAC and IFORS, May 28-31, 1973, Algiers, Algeria.

FIGURE 2
An Example of a Logical Framework

NARRATIVE SUMMARY	OBJECTIVELY VERIFIABLE INDICATORS	MEANS OF VERIFICATION	IMPORTANT ASSUMPTIONS
Program or sector goal: Provide universal education geared to needs of Temasek	Measures of goal achievement: (a) Degree of shortage/surplus in various professions	(i) Questionnaires to major industries (ii) Comparison of number of students graduated with objective in 10-year plan	Assumptions for achieving goal targets: Ability of economic sector to provide jobs predicted in 10-year plan
Project purposes: 1. Meet the educational needs of a rural agricultural community	Measures of purpose achievement: (a) Number of students from rural and urban areas proportionate to the population of potential students (b) Research and course directions in School of Agriculture	(i) Demographic data (ii) Opinions of leaders of rural interest groups	Assumptions for achieving purpose: Ability of primary and secondary schools in rural areas to provide students with an adequate foundation for tertiary education
Outputs: 1. Students with degrees in: Agriculture, Science, Engineering	Magnitude of outputs: 500/year 100/year 200/year	Data collection by university	Assumptions for providing outputs:
Inputs: 1. Faculty 2. Students 3. Scholarship program	Implementation target: *Type* — *Quantity* PhD in Ag. — 9 MS in Ag. — 5 MS in Science — 5 PhD in Engr. — 10	Data collection by university	Assumptions for providing inputs: Brain drain is cut by half in five years

1. **Complete the vertical logic.**
Determine at each lower level the conditions which are necessary and sufficient to achieve the next upper level (see figure 1). The inputs must be necessary and sufficient to produce all the outputs; the outputs must be necessary and sufficient to achieve the purposes, etc. For example, for the construction of irrigation canals covering 2,000 acres (output), there could be several inputs: "20 shovels," "farmer support," and an "irrigation engineer." The analyst must be sure that each input is necessary to achieve the construction of the canals. He should determine if the inputs are sufficient or if some are missing.

2. **Complete the horizontal logic.**
   2.1 At each level of the vertical logic, complete the three part horizontal logic. Determine:
      a) Objectively verifiable indicators which demonstrate that the desired end has been accomplished.
      b) Means of verification, or specific mechanisms through which accomplishment is objectively verified.
      c) Important assumptions which affect the success of the project. Here, the project designer explicitly identifies the uncontrollable factors that may affect project success.
   2.2 Consider objectively verifiable indicators which may or may not be quantifiable. The two step "clarification of evidence" involves identifying first the indicator and then the means of verification. The project designer is encouraged to measure what is important, rather than what is easy to measure.
   2.3 Follow each of the vertical logic levels through the horizontal logic. For instance, after the purpose of the project has been established, fill in the conditions which indicate that the purpose has been achieved according to the means of verification. There may be many indicators which point to success at the purpose level since a single indicator is seldom sufficient to signal success.
   2.4 State the assumptions which underlie the achievement of the project purpose.

EXAMPLE

Consider the educational sector in the country of Temasek. Currently, there is a National University in Bandar Besar, the capital, which is attended mainly by students from urban areas. The northern rural areas, with strong agricultural needs, do not receive enough agricultural education from this university. A project is undertaken to establish a university at Bandar Kechil to serve that area's needs. Figure 2 shows a partially completed Logical Framework for this project.

THEORY

The Logical Framework technique is based on a systems planning model. The vertical logic closely relates to the System Definition Matrix (SDM, page 67). Some theoretical work has been done on identifying social indicators and objectively verifiable indicators (see, for example, DeGreene, 1973).

BIBLIOGRAPHY

DeGreene, K. A. *Sociotechnical Systems Factors in Analysis, Design and Management*. Englewood Cliffs, N.J.: Prentice-Hall, 1973.

USAID, Office of Program Evaluation. *Evaluation Handbook*. 2d. ed. Washington, D.C.: United States Agency for International Development, 1974.

Rosenberg, Leon J., and Hageboeck, Molly. "Management Technology and the Developing World." In *Systems Approaches to Developing Countries*, Proceedings of the Symposium sponsored by IFAC and IFORS, May 28-31, 1973, Algiers, Algeria.

List of Cross-References

Benefit-Cost Ratio
CBA, CFA, DIS, IPX, IRR, NPW, SVY
Brainstorming
CBA, DTR, NGT
Cash Flow Analysis
BCR, CBA, CEA, DIS, IPX, IRR, NPW, SVY
Computer Simulation Models
DTB, FLW, GAM, IMD, OVD, QTN, SVY
Contingency Analysis
CBA, CEA, DTR, IDL, MCU, PPM, SCN, SPA
Cost-Benefit Analysis
BCR, CEA, CFA, DIS, IMD, IPX, IRR, MPA, NPW, OBT, OVD, PPB, RTS, SDM, SVY
Cost-Effectiveness Analysis
BCR, CBA, CFA, CGA, CSM, DIS, DLP, IRR, OBT, RTS
Critical Path Method
CGA, GNT, SVY
Decision Tables
CSM, FLW, IRR
Decision Trees
CGA, MCU, SPA, SVY, TRD
Delphi
HIS, NGT, QTN
Discounting
BCR, CFA, IRR, NPW
Exponential Smoothing Forecasts
RGF
Flowcharts
DTB, IMD, SCN, SDM
Function Expansion
BSG, IDL, NGT, SDM
Gaming
CGA, CSM, IMD, OVD, SCN, TRD
Gantt Charts
CPM, SVY
Histograms
DLP, RTS, SPA, SVY
IDEALS Strategy
BSG, CBA, FEX, NGT, SDM
Impact-Incidence Matrix
BCR, FEX, INS, MCU, OVD, SVY
Intent Structures
BSG, DLP, FEX, IMD, NGT, OBT, TRD
Interaction Matrix Diagramming
BSG, DLP, NGT, OVD, RTS, TRD
Internal Rate of Return
BCR, CBA, CFA, DIS, DTB, IPX, NPW
Interviews
BSG, HIS, NGT, QTN, SVY
Logical Framework
IMD, OBT, OBD, SDM
Morphological Analysis
CGA, DLP, IMD, NGT, SCN, SDM, TRD
Multiple Criteria Utility Assessment
CEA, CGA, DTR, OBT, RGF, RTS
Net Present Worth
CBA, CFA, DIS, IRR
Nominal Group Technique
BSG, DLP, RTS
Objective Trees
IMD, INS, IVW, LGF, NGT, PPB, RTS, SVY, TRD
Organizational Climate Analysis
IVW, OBT, QTN, RGF, RTS
Oval Diagramming
CSM, FEX, IMD, LGF, SCN, SDM, TRD
Planning, Programming, and Budgeting
BCR, CBA, CEA, DIS, DLP, FEX, INS, LGF, MPA, OBT
Program Planning Method
NGT
Questionnaires
CBA, DLP, HIS, IVW, SVY
Rating Scales
CBA, CGA, DLP, DTR, MCU, NGT, SPA
Regression Forecasting
OVD, SVY
Scenarios
DLP, GAM, OVD
Subjective Probability Assessment
DLP, DTR, IVW, RTS
Surveys
CBA, CEA, DLP, GNT, HIS, IVW, QTN, RGF, RTS
Synectics
NGT, RTS
System Definition Matrix
BSG, CBA, CSM, FEX, GAM, IDL, LGF, NGT, SCN
Tree Diagrams
DTR, IMD, OBT, OVD

Glossary

ACTION STUB. That portion of a decision table which lists the actions or decisions to be taken if a particular combination of circumstances occurs (DTB).

ACTION-EVENT PATH. The sequence of alternative actions and relevant events represented by the branches in a decision tree (DTR).

ACTIVITY. An operation with a well-defined beginning and end and a specific purpose (CPM).

AND LOGIC ELEMENT. Links sub-objectives to objectives where all sub-objectives must be achieved in order to attain the higher level objective(s) (INS).

ANNUAL CASH FLOW. The net incremental benefits for each year of a project and the difference between the incremental benefits and costs (CFA).

ASSESSOR. A person who estimates the probability distribution of a set of events (SPA).

ATTRIBUTE. The elements or components of the system and the interrelationships among them (MPA, SCN).

AXIOLOGICAL MEASUREMENT. Involves value judgments, where the data necessary to determine accomplishment of an objective are gathered via subjective methods (OBT).

BASE SYSTEM STATE. The set of current conditions which describes the essential characteristics of the scenario (SCN).

BINARY-EVENT OBJECTIVE. An objective that either clearly occurs or does not occur (OBT).

BRANCHING RULE. A rule that governs the construction of relationships in a tree diagram (TRD).

CAUSAL CHAIN. A sequence of cause and effect relationships between variables (OVD).

CAUSAL LOOP. A causal chain which is connected so that a change in any variable eventually feeds back through the chain to affect this variable (OVD).

CENSUS. A survey of all members of a subject population (SVY).

CENTRAL TENDENCY. The most likely, or average value of the variable (HIS).

CHECKLIST. Used in design or analysis where items are marked or otherwise noted item by item (SDM).

CLASS INTERVAL. A uniform division of the variable range (HIS).

CLOSED QUESTIONS. Questions which require the respondent to limit responses to prespecified categories (QTN).

CLUSTER SAMPLE. The process of randomly selecting several clusters of subgroups from the total population and surveying all members of the selected subgroups (SVY).

CLUSTERED DATA. Used to aggregate the data into fewer points for analysis and plotting (HIS).

COMPONENTS. An entity in a system which may be elemental, or it may be a subsystem having distinct components (SDM, TRD).

CONDITION ENTRIES. The conditions of each factor (or question) listed in the condition stub (DTB).

CONDITION STUB. That portion of a decision table which lists the factors to be considered when making decisions in a given situation. Each factor is written in the form of a question (DTB).

CONTINGENCY. A particular combination of factors that describes a future environment (CGA).

CONTINUOUS MODEL. A model which treats variables that change continuously over time (CSM).

CONTINUOUS VARIABLE. Takes on an infinite number of values over some range of possible values (HIS).

CONTROL DIMENSION. Evaluates and regulates any element's specification. This dimension measures each element as the system operates, compares the measure to what is designed or desired, and takes action if the difference is greater than desired (SDM).

CORRELATION. An observed relationship between two or more variables in which the changes in one variable may be associated with predictable changes in another, the relationship, however, is not necessarily cause-effect (OVD).

CORRELATIVE BEHAVIOR. An assumed relationship between two or more variables in which the changes in one variable may be associated with predictable changes in the others (RGF).

CRITICAL ACTIVITY. An activity which, if not completed on time, will delay the entire project (CPM).

CRITICAL PATH. The sequence of critical activities from project start to project finish that determine the shortest project duration (CPM).

CROSS-INTERACTION MATRIX. A representation of relationships between dissimilar sets of variables (IMD).

DECISION RULES. The action entries of a decision table which link a particular combination of condition entries to specified actions (DTB).

DECISION SYMBOL. Represents a step in a process where there is a choice among two or more alternative actions (FLW).

DEPENDENT VARIABLE. The variable being forecast (RGF).

DESCRIPTIVE MODEL. A representation or imaginary entity containing information in a predefined form, intended to be interpreted by its user rules (SDM).

DETERMINISTIC MEASUREMENT. Where the realization of the objective is unequivocally determined from numerical data (OBT).

DIMENSION. Collections of attributes of the system, where each collection represents a major aspect of the system (SCN).

DIRECT ANALOGY. Compares the problem being faced to a parallel situation in another field, technology, or discipline (SCN).

DIRECT ANALOGY METHOD. Used in Synectics sessions when members compare the problem being faced to a parallel situation in another field, technology, or discipline (SYN).

DIRECT EFFECT. An interaction between two variables so that a change in one results in a similar change in the other (OVD).

DIRECT MARKET VALUES. Measures of project costs or benefits which are assessed from equivalent market prices (IPX).

DIRECTED LINE. Links two symbols together with an arrowhead indicating the sequence (FLW).

DIRECTED RELATIONSHIP. Specifies that the existence of the relationship is dependent on the order in which the two elements are considered (IMD).

DISCOUNT FACTOR. A fraction between 0 and 1 which gives the present worth of one monetary unit spent or received (DIS).

DISCOUNT RATE. A percentage rate (usually annual) which equates the present and the future worth of a payment (DIS).

DISCOUNTED CASH FLOW. A single value which represents the present worth of the net incremental benefits estimated for each project year (NPW).

DISCRETE STOCHASTIC MODEL. A model which describes the changes in variables at definite points in time (CSM).

DISCRETE VARIABLE. A variable with only a finite number of values which are multiples of a basic unit (HIS).

DRIVING FORCE. An attribute of a system which causes changes in the system state over time (SCN).

DUNNING. The process for recontacting participants who have failed to return their questionnaires (DLP).

DURATION. The estimated time needed to perform the activity (CPM).

DYNAMIC BEHAVIOR. A consequence of delayed interactions among system variables. The dynamic state of a system depends on the prior values of state variables (OBT, RTS).

EARLIEST FINISH (EF). The sum of an activity's earliest start time and its duration (CPM).

EARLIEST START (ES). The earliest time (measured from the start of the project) when an activity may begin, assuming all immediate predecessors are completed (CPM).

ECONOMIC ANALYSIS. Analysis from the viewpoint of the national government and the economy (CFA).

EFFECTIVENESS. The degree to which the project or system design objectives are achieved (CEA).

ELEMENT. Part of a problem situation which can be described by all its elements (MPA).

ELSE RULE. A column in a decision table which applies when no other decision rules may be added to cover the case or where no combination of conditions applies (DTB).

ENVIRONMENT. The set of all factors which are salient to the understanding of systems relationships, but which are outside the influence of the system variables (OBT, SDM).

EVENT. A future outcome, the occurrence of which is uncertain (SPA).

EXTERNAL CONTEXT. Represents the constraints on the base system (SCN).

FANTASY ANALOGY. The participant's wishful thinking that the problem may solve itself or cease to exist (SYN).

FEEDBACK STRUCTURE. The set of relationships describing a system that involves one or more interlocking causal loops (OVD).

FINANCIAL ANALYSIS. Analysis from the viewpoint of the individual, group, or business which will directly gain or lose because of the project (CFA).

FREQUENCY DISTRIBUTION. Plots the frequency of different categories of response (QTN).

FUNCTION. The primary concern of the system. It is the fundamental dimension of purpose (FEX, IDL, SDM).

FUNCTION HIERARCHY. An ordering of system functions from the most specific to the broadest (FEX).

FUNDAMENTAL DIMENSION. The basic characteristic of the eight system elements (SDM).

GOAL. A value judgment which satisfies one or more needs (FEX, LGF, SCN).

GOVERNING RULES. Describe the relationships between decisions made by the participants in a game and the resulting changes in the simulated environment (GAM).

HIERARCHY. An ordered structure illustrating which factors are subordinate to others (TRD).

HUMAN AGENTS. The personnel who may be necessary for the system to achieve its function, yet are not themselves inputs or outputs of the system (SDM).

IDEAL SYSTEM. A system that achieves the function in the best possible manner as judged by the criteria for evaluating the system. Such systems typically require the least possible cost, the least amount of human resources, and the least time while providing maximum benefits (IDL).

IMMEDIATE PREDECESSOR. Any activity which immediately precedes an activity and which must be completed before the activity can start (CPM).

IMMEDIATE SUCCESSOR. Any activity which immediately follows an activity and which may not start until completion of the activity (CPM).

IMPORTANT ASSUMPTIONS. The factors which affect the success of a project and which are beyond the influence of the decision maker (LGF).

INCREMENTAL COSTS AND BENEFITS. Computed by subtracting the "without project" values from the "with project" values (CFA).

INDEPENDENT VARIABLE. The non-random variable which is used for forecasting other variables using regression (RGF).

INFLUENCE RELATIONSHIP. When one variable's change in value influences change in another variable (TRD).

INFLUENCE TREE. A tree that diagrams the variables which influence other variables which are higher in the tree (TRD).

INFORMATION CATALYSTS. The communication (written or verbal) and the knowledge which enable the system process to occur, yet which are not inputs or outputs of the system (SDM).

INPUTS. The people, information, and/or physical items which enter the system to be transformed by a sequence into outputs of the system (LGF, SDM).

INTERACTING GROUP. A process that permits discussion among participants (NGT).

INTERFACE DIMENSION. The relation to other systems or elements—a linking entry to related system definition matrices (SDM).

INTERMEDIATE IMAGE. An intermediate image describes the state of the system after a time interval *n* (SCN).

INTERNAL ECONOMIC RETURN. The rate of return derived from an economic analysis of the benefits and costs to the society or economy of the country (IRR).

INTERNAL FINANCIAL RETURN. The rate of return derived from a financial analysis of the project cash flow (IRR).

INTERVAL SCALES. Scales that reflect not only the rank of one factor over another, but the degree to which one exceeds the other. The difference between them corresponds to a length of scale interval (RTS).

INTERVIEW SCHEDULE. The plan for conducting an interview. It includes the questions to be asked (IVW).

INVERTED EFFECT. An interaction between two variables so that a change in one results in an opposite change in the other (OVD).

IRREVERSIBLE VARIABLE INTERACTION. When the variable only increases or only decreases (OVD).

LATEST FINISH (LF). The latest time (measured from the start of the project) when an activity may be completed without delaying any immediate successor(s), thereby delaying completion of the project (CPM).

LATEST START (LS). An activity's latest finish time minus its duration (CPM).

LIMITED ENTRY. A type of decision table which permits only a limited set of condition and action entries in the decision rule columns (DTB).

LINEARLY LINKED MATRICES. Matrices with a common set of rows or columns (IMD).

LOGIC ELEMENT. A symbol indicating the nature of the relationship between two or more objectives at adjacent levels in a hierarchy (INS).

LOGICAL INCONSISTENCIES. When hypothesized relationships among variables are inconsistent (OVD).

LOGICAL MEASUREMENT. Determines whether a binary-event objective has or has not occurred (OBT).

MATRIX. A mathematical and graphical representation in two dimensions (IMD).

MATRIX ENTRY. The symbol used to indicate the existence or absence of a relationship between the element in the row and the element in the column (which together define the entry) (IMD).

MEAN. The average value or central tendency of the data (HIS).

MEANS OF VERIFICATION. The specific mechanisms by which quantitative indications of the accomplishment of a project may be observed (LGF).

MEANS-ENDS ANALYSIS. The identification of alternative actions to achieve specified ends (OBT, TRD).

MEASURING INSTRUMENT. A technique for eliciting and measuring responses from a subject (OCA, SVY).

MEDIAN. The value corresponding to the midpoint of the data points (HIS).

MILESTONE. A point in time (specific date) which marks the completion of a sequence of activities or the beginning date for subsequent activities (CPM).

MIXED ENTRY. A type of decision table which permits extended entries such as a range of values for a question in the condition stub (DTB).

MODE. The value or class interval which occurs most frequently (HIS).

MODEL. A representation of an imaginary entity that contains information in a certain predefined form and has specified rules for interpretation (TRD).

MULTIPLIER EFFECT. Occurs when a project impact on one aspect of an economic system generates a stimulating effect on other aspects (IPX).

MULTI-STAGE SAMPLING. Draws random samples in stages (SVY).

MUTUALLY-CAUSAL VARIABLES. Variables that occur when a change in one variable causes a change in another which is fed back to affect the first (OVD).

MUTUALLY-EXCLUSIVE PROJECTS. Incompatible alternatives where implementing one precludes implementing the others (NPW).

NOMINAL GROUP. A group process in which the members work independently but in each other's presence (NGT).

NOMINAL SCALES. Scales that categorize different factors (RTS).

OBJECTIVE. A specific statement of purpose expressing a desired end (INS, OBT).

OBJECTIVELY VERIFIABLE INDICATORS. Indicators that demonstrate that certain desired results are being accomplished (LGF).

OPEN QUESTIONS. Questions which permit the respondent to answer as he or she chooses (QTN).

OPPORTUNITY COST. The cost of committing resources to a particular use as measured by the highest return that could have been obtained by committing the same resources to an alternative use (DIS).

OR LOGIC ELEMENT. Links objectives where the attainment of any one or a combination of sub-objectives will achieve the higher level objective (INS).

ORDINAL SCALES. Scales used to rank-order a set of similar objects along a criterion dimension which reflects a basis for comparison, but not the degree of difference (RTS).

ORGANIZATIONAL ATTRIBUTES. The elements or components of an organizational system and the interrelationships among them (OCA).

ORGANIZATIONAL CLIMATE. The relatively enduring quality of the internal environment of an organization that (a) is experienced by its members, (b) influences their behavior, and (c) can be described in terms of the values of a particular set of characteristics (OCA).

ORTHOGONALLY LINKED MATRICES. Matrices with the same set of elements in the rows of one matrix and the columns of the other matrix (IMD).

OUTPUT. The desired and the undesired results of the transformation process of a system (FEX, LGF, SDM).

OWNER. An organization or person who possesses intent for, or has a vested interest in, a project (INS).

PARAMETER. A quantity with only one value over the entire range of the system behavior being simulated (CSM).

PARTICIPANT OBSERVATION. The gathering of information about and impressions of a selected group by direct interaction over an extended period of time (SVY).

PAYOFF VALUES. Represent the gain resulting from the occurrence of a particular action-event path (DTR).

PERIOD. The time interval between successive observations of the underlying process (EXF).

PERSONAL ANALOGY METHOD. Used in Synectics sessions where a group member identifies with an element of the problem and looks at it as though he were that element (SYN).

PHYSICAL CATALYSTS. The equipment, facilities, etc. which are necessary for the inputs to be transformed into outputs, but which are not themselves inputs or outputs of the system (SDM).

POLICY. Long-range decisions which influence a large number of diversified groups with different values. Policy made at one level of an institution forms the guiding criteria for shorter-range decisions at a lower level (INS).

PREDECESSOR ACTIVITY. An activity that must be completed before another activity can start (CPM).

PRESENT WORTH. The value today of a future payment (DIS).

PROBABILISTIC MEASUREMENT. Occurs when the attainment of the objective may not be determined with certainty (OBT).

PROBABILITY DENSITY FUNCTION. Represents the probability distribution of a set of continuous events (SPA).

PROBABILITY DISTRIBUTION. Associates each event in the set with its probability of occurrence (SPA).

PROBLEM ENVIRONMENT. The set of variables and relationships which are germaine to the decision process under study (GAM).

PROCESS SYMBOL. Represents an action which takes place over time (FLW).

PRODUCER-PRODUCT RELATIONSHIP. When one variable is a product of the other (TRD).

PROGRAM CATEGORY. A system category under which specific projects, or program subcategories, are developed (PPB).

PROGRAM ELEMENTS. The resources or inputs needed to carry on a project (PPB).

PROGRAM SUB-CATEGORY. Refers to the specific projects considered under a program category (PPB).

PROJECT EFFICIENCY. The ratio of project outputs to inputs (BCR, CEA).

PURPOSE. A project's primary intention or aim (LGF).

QUALITATIVE OBJECTIVE. Objectives that are judged subjectively to determine if they have been accomplished (OBT).

QUANTITATIVE OBJECTIVE. An objective that represents a quantifiably verifiable end or result (OBT).

RANK-ORDERING. The process of weighing one item against others and then ordering the items by weight on a scale such as importance or priority (BCR, NGT, NPW, FPM).

RATE DIMENSION. The performance measure for a system element (SDM).

RATIO METHOD. Estimates probabilities for a set of events by first obtaining the relative chance of pairs of events for all possible pairs (SPA).

RATIO SCALE. An interval scale for which the dimension of comparison has a natural zero point (RTS).

REDUCED MATRIX. A matrix formed by omitting one or more rows or columns from the original matrix (IMD).

REFLEXIVE RELATIONSHIP. Occurs when the variable interacts with itself (IMD).

REGRESSED VARIABLE. A variable is regressed on another when the former is dependent on the latter (RGF).

REGRESSION COEFFICIENT. The coefficient of the independent variable in a regression equation (RGF).

REGULARITY. The most frequent or dominant (and occasionally the most important) condition of concern to the project design (IDL, FEX).

RELATIVE CHANCE. Reflects whether one event will occur rather than another (SPA).

RELEVANCE TREE. A tree that diagrams the relationships among different sets of factors at each level of a hierarchy (TRD).

ROUND-ROBIN. A process for serially recording ideas where each participant provides an idea in turn. No discussion occurs, although the leader may ask for a show of hands on how many participants had a similar idea. Those responding then eliminate that idea from their respective lists. The process may continue in a circular fashion until all participants' lists are exhausted (NGT).

SAMPLE. A subset selected from a subject population, the attributes of which are assumed to hold true for the total population (SVY).

SAMPLE STATISTIC. A quantitative parameter which characterizes some aspect of the population from which a set of data are drawn (HIS).

SCORING. Used in games as feedback to the participants to reflect the effectiveness of their decisions (GAM).

SECTOR. The larger system of which a project is part (LGF).

SELF-INTERACTION MATRIX. A representation of relationships within a single set of variables (IMD).

SEQUENCE. The process by which the inputs are worked on, transformed, or processed into outputs, usually with the aid of catalysts (SDM).

SET. A collection of elements having some common property (IMD).

SET OF CONTINUOUS EVENTS. Consists of an infinite number of events (SPA).

SET OF DISCRETE EVENTS. Consists of a finite number of mutually-exclusive events (SPA).

SHADOW PRICES. Adjusted market prices which reflect the true benefit or cost to the economy (CFA).

SIMPLE RANDOM SAMPLE. A sample made so that every member of the target population has an equal probability of selection (SVY).

SLACK. The amount of leeway allowed in either starting or completing an activity (CPM).

SMOOTHED VALUE. An estimate of the average value of the variable being forecast (EXF).

SMOOTHING CONSTANT. A fraction between 0 and 1 that indicates the degree of confidence placed on the most recent datum (EXF).

SOLUTION COMPONENT. The part of a program that is proposed as the solution (PPM).

STANDARD DEVIATION. The measure of the dispersion of the data values about the mean (HIS).

STATE DIMENSION. A specification of anticipated changes and plans in specific time horizons for each of the four dimensions (SDM).

STATE SCENARIO. Describes conditions and events (the state of the system and the external context) at a single future point in time (SCN).

STATE SYMBOL. Represents a tangible product, requirement, or specific condition associated with a process sequence (FLW).

STOPPING RULE. A rule that determines when any branch of the tree diagram should end (TRD).

STRATEFIED SAMPLE. A sample that selects a proportional sample at random from each of the groups in a stratification of the total population (SVY).

SUBJECT POPULATION. The set of all events or entities which possesses certain specified characteristics (SVY).

SUBJECTIVE PROBABILITY. A quantified judgment of the chance of an event occurring (SPA).

SYMBOLIC ANALOGY METHOD. Describes the problem by objective and impersonal titles. These titles are used to identify other problems which may be described by the same title. They are generally expressed in two words, usually describing two conflicting attributes of the problem (SYN).

SYMMETRICAL RELATIONSHIP. Occurs when the relationship between two elements is non-directed (IMD).

SYSTEM. A collection of components which interact to achieve a common function (CEA, CSM, FEX, IDL, SCN, SDM, TRD).

TARGET GROUP. A set of persons with certain common characteristics (DLP, OCA).

THRESHOLD EFFECT. When one variable does not change until the other variable changes significantly (OVD).

TIME PREFERENCE. The general preference of individuals for present over future receipts and for future over present expenditures (DIS).

TOTAL CASH FLOW. The sum of all annual cash flows for the life of the project; an undiscounted measure of the aggregate change expected from implementing a project (CFA).

TRANSIENT SCENARIO. Forecasts changes in and the alternative actions on a system at various stages in the evolution of the system (SCN).

TRANSITIVE RELATIONSHIP. Requires that a directed relationship among three or more elements be consistent (IMD).

TREE GRAPH. A set of linked elements where only one exists between any two factors (OBT, TRD).

TUNING. The process of making changes in the parameters and initial values for variables in order to minimize the errors between expected and actual simulation output or between observed or simulated data (CSM).

UTILITY. A quantitative expression of the worth or satisfaction associated with an outcome (DTR, MCU).

UTILITY FUNCTION. Associates the possible levels a criterion may take with the utilities for those levels (MCU).

UTILITY MATRIX. Presents the elements of a decision under certainty (MCU).

VALIDATION. Testing whether a computer simulation program simulates the observed system behavior. It is a process of simulating the past and checking the simulated data against actual data (CSM).

VARIABLE. A factor used to describe a system which may change value as a function of time (CSM, OVD).

VERIFICATION. Testing a computer simulation program to see that the program functions as intended. It is a process of eliminating logical errors in the program (CSM).

XOR LOGIC ELEMENT. Links mutually exclusive sub-objectives to the higher level objective(s). The achievement of one sub-objective alone achieves the higher level objective (INS).

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