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Chapter 6 describes tools which give the project planner the methods for dealing with uncertainty and aggregating information into statistical data which summarize the variability of the data. The four techniques discussed give the project designer a grasp on the inherent variability of the development process. Histograms diagram alternative outcomes which permit the inspection of patterns and quantification of sample statistics. Subjective Probability Analysis quantifies expert judgments about the change of specific events occurring. Two techniques (Decision Trees and Contingency Analysis) enable the analyst to deal with alternative outcomes of a project. The Decision Tree technique accounts for alternatives by representing and analyzing the choice of action and the expected outcome for each choice. Contingency Analysis helps a decision maker choose among alternative plans designed for various contingencies.

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# 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.

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# 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 these 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 im-

portant 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

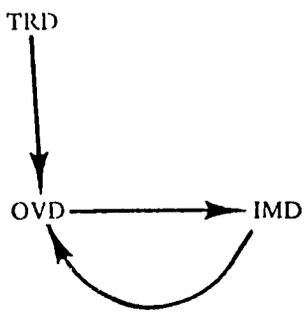
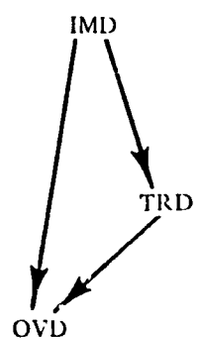
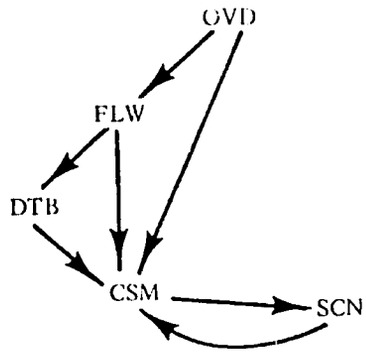



FIGURE 1b



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



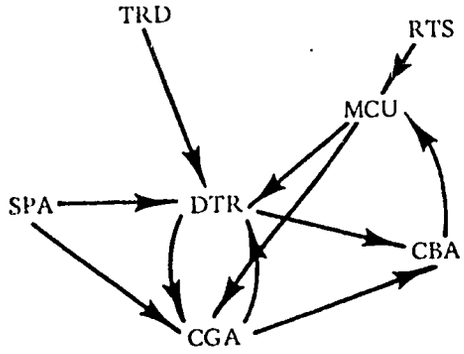

## GENERATING AND ANALYZING ALTERNATIVE PLANS OF ACTION

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

FIGURE 3




## 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

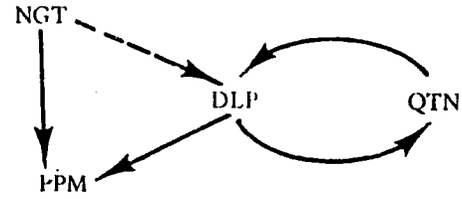
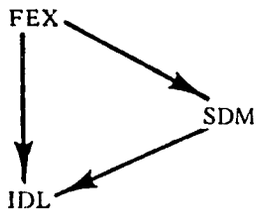


FIGURE 5




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.

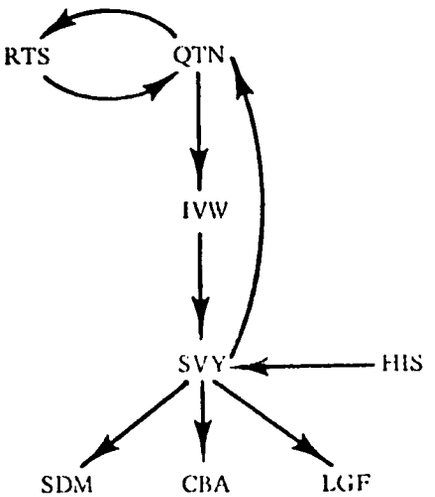
Focusing on function rather than on problems gets people involved in a constructive assessment of what should be, rather than what's wrong and who's to blame. There are sound arguments for both approaches. The IDEALS Strategy often comes under attack because its emphasis on normative specification may 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

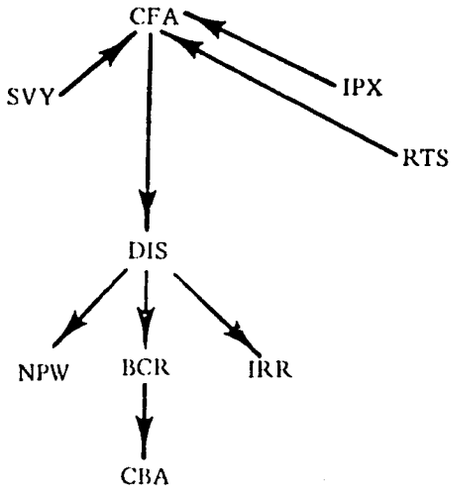
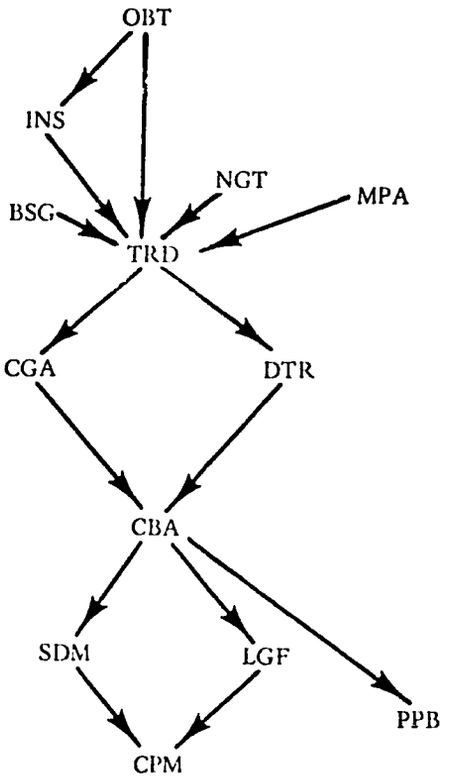



FIGURE 8




## THE "CONVENTIONAL" SYSTEMS APPROACH

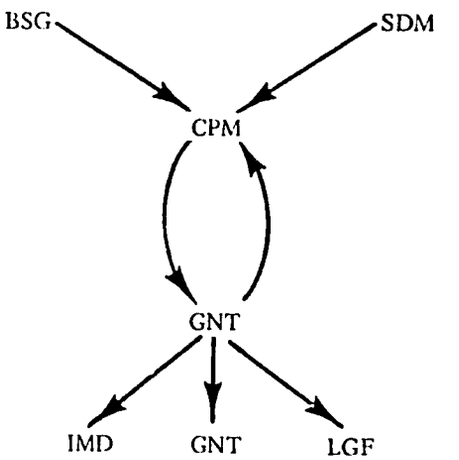
Systems analysis begins with identifying objectives, specifying alternative means, specifying the criteria for selecting among the alternatives, and then synthesizing a system or plan from the choices. A sequence of techniques for applying the systems analysis strategy begins with Objective Trees (OBT, 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

FIGURE 9




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

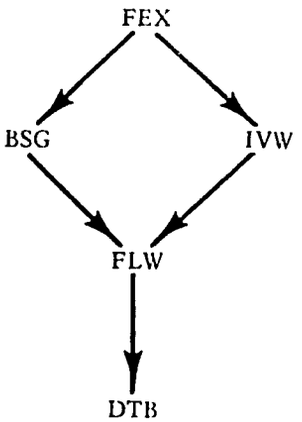
Framework may also be used to sharpen the identification of objectively identifiable indicators of progress. These milestones are shown as vertical lines on specific dates of the Gantt Chart and written on the Critical Path Method network at the appropriate nodes.

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

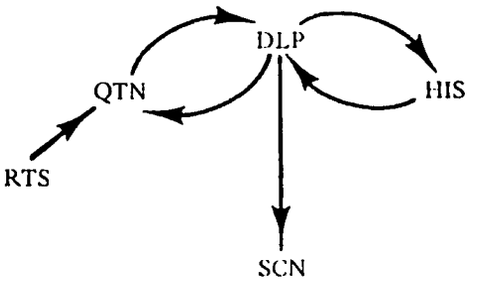



The results of this analysis are presented in the form of flowcharts (FLW, page 107) or decision tables (DTB, page 113). The flowchart uses different symbols to display and analyze complex processes. The decision table presents the decision as a preprogrammed process by specifying the conditions which 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

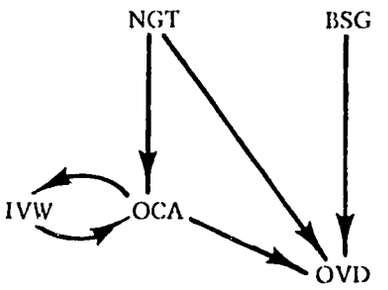



The Delphi technique (DLP, page 168) begins by directing questionnaires to a selected group of prognosticators. The results of each round are summarized for the Delphi group, often in the form of a histogram which aggregates the individual judgments. Rating scales attempt to quantify priorities and opinions. 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 interview-

ing 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.

# 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

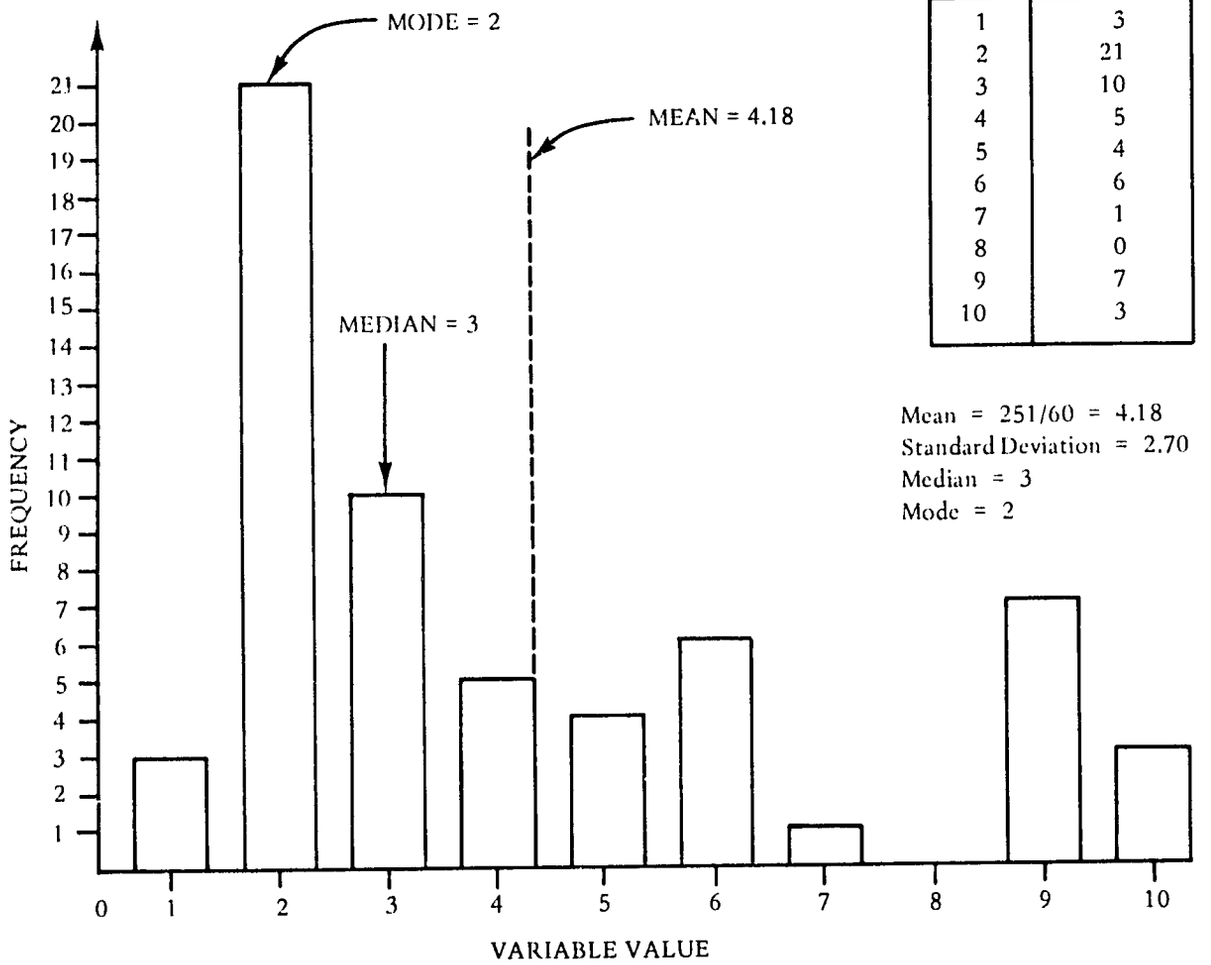
A histogram plots the frequency with which different values of a variable occur (see figure 1). If the variable is discrete, the histogram may be a series of bars centered over each value. If the variable is continuous over some fixed range or if discrete values are grouped, the histogram is a series 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

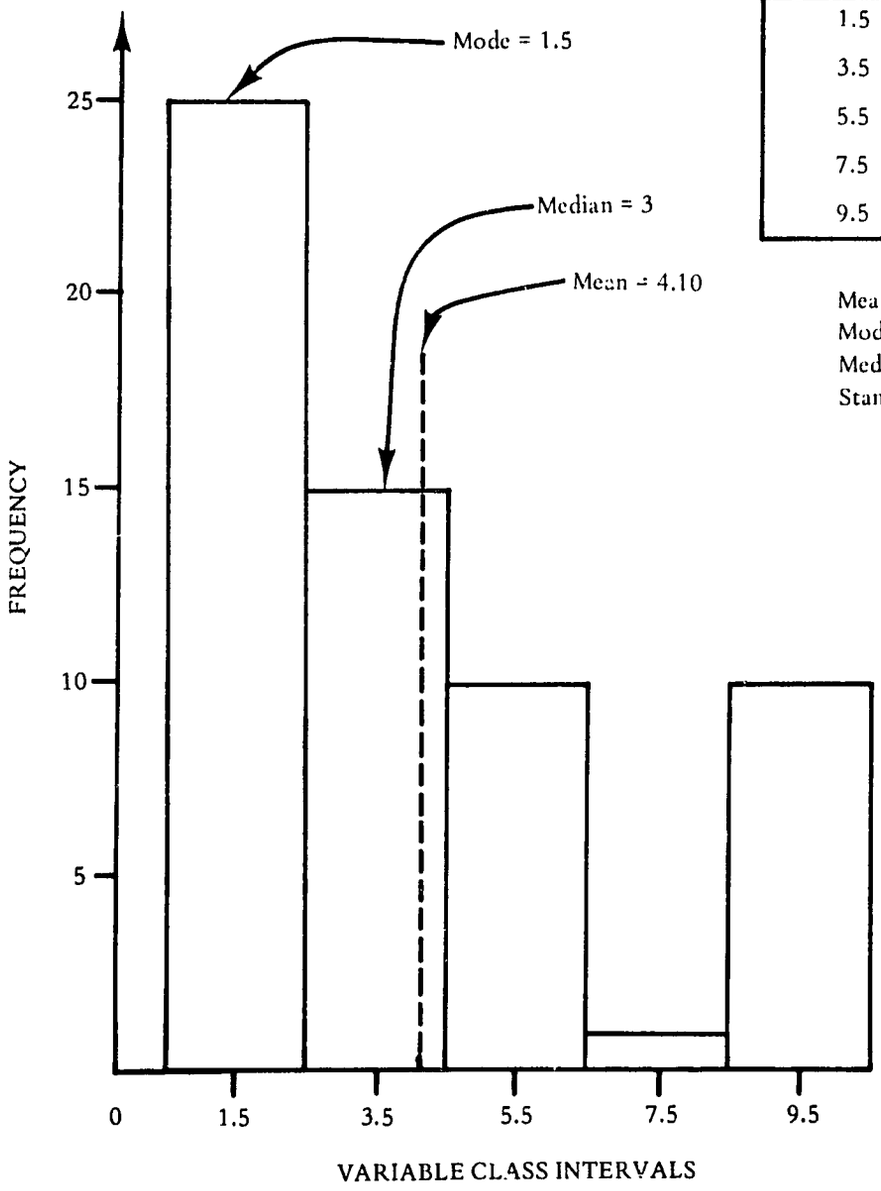
### SUPPLEMENTAL DEFINITIONS

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 midpoint 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<br>2<br>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.

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**FIGURE 4**
**Mean of Grouped Data**

| CLASS INTERVAL | | Midpoint | Frequency | Midpoint X Frequency |
|---|---|---|---|---|
| Lower Limit | Upper Limit | | | |
| 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

$$*\text{STANDARD DEVIATION} = \text{SIZE OF CLASS INTERVAL} \times \sqrt{[(SUM_3/SUM_1) - (SUM_2/SUM_1)^2]} = 3.05$$

# 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

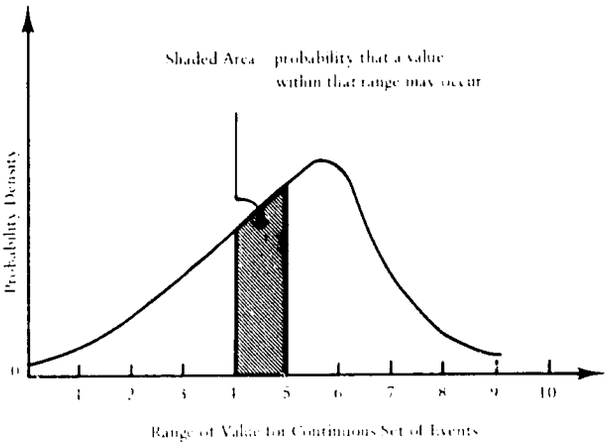
Considering a set of ten events takes about 30 minutes. The time required depends on the number of events.

## 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:

   $$P(x_1) / P(x_2) = 3/2 \qquad [1]$$

   or

   $$P(x_1) = 1.5 \times P(x_2) \qquad [2]$$

   where
   $P(x_i)$ = probability of event $x_i$, $i = 1, \ldots, n$

   2.2 Similarly, he may assess:

   $$P(x_2) / P(x_3) = 1/2 \qquad [3]$$

   or

   $$P(x_2) = 0.5 \times P(x_3) \qquad [4]$$

   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:

   $$\begin{aligned} P(x_1) / P(x_3) &= [P(x_1) / P(x_2)] \times [P(x_2) / P(x_3)] \\ &= 3/2 \times 1/2 \\ &= 3/4 \qquad [5] \end{aligned}$$

   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:

   $$P(x_1) + P(x_2) + P(x_3) = 1.0 \qquad [6]$$

   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:

*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 "$x_1, x_2, \ldots, x_n$.

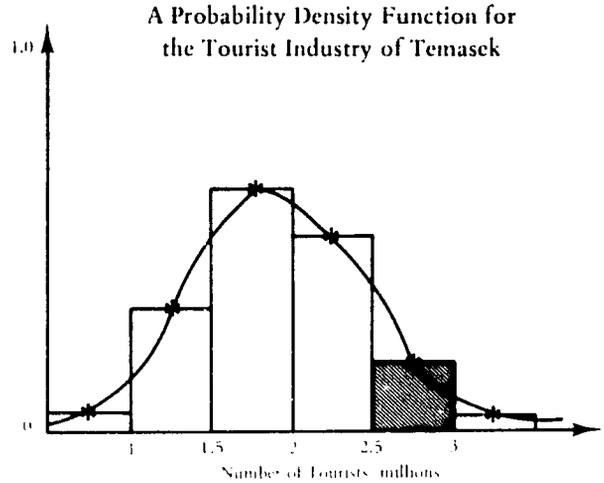
2. Assess relative changes (see discrete case, step 2).
3. Check inconsistencies (see discrete case, step 3).
4. Compute the probability distribution (see discrete case, step 4).

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.

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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 benefit 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

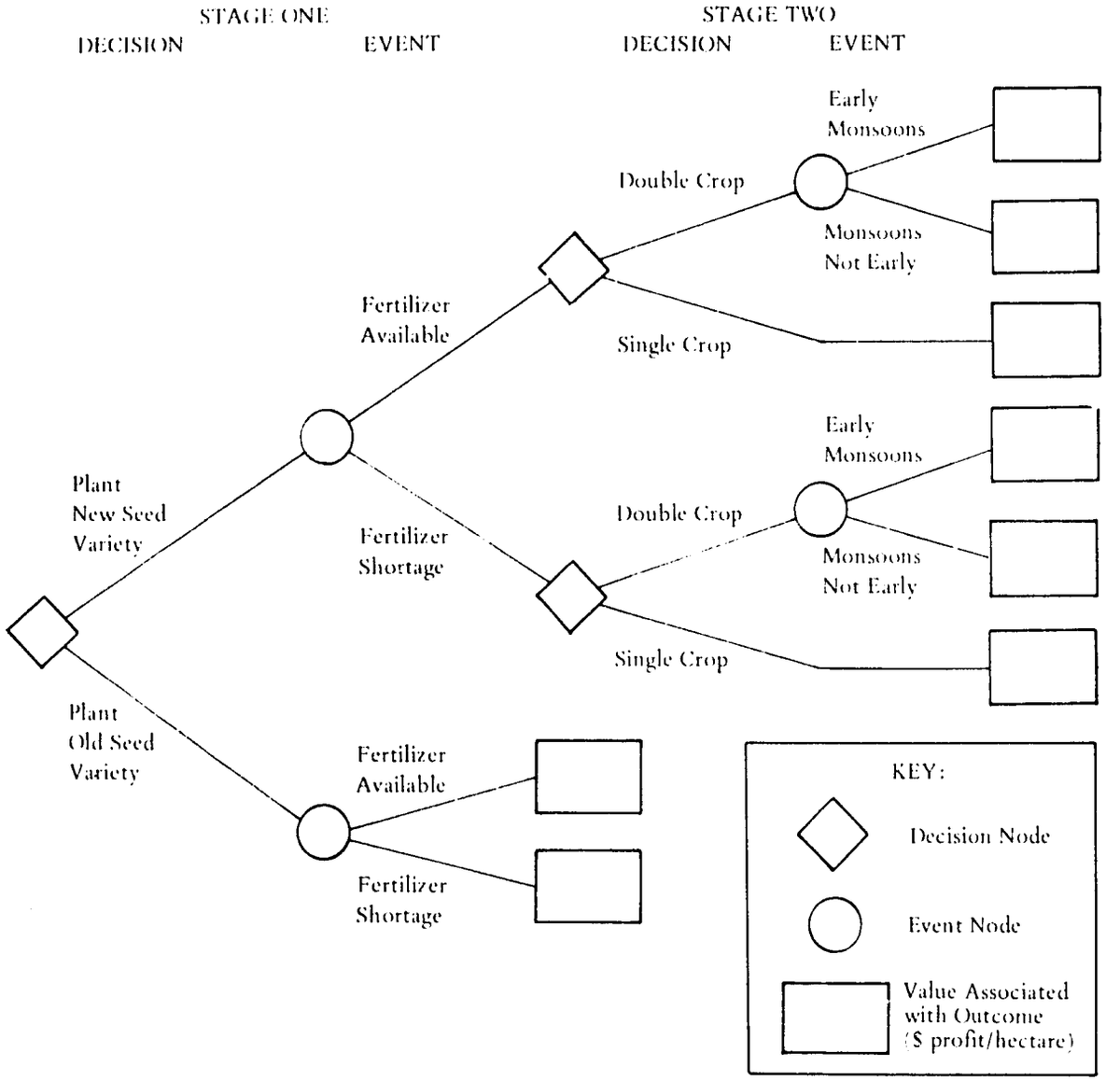
A decision tree diagrams alternative choices available in a decision-making situation, the events which affect each alternative, and the *payoffs* that would result from making the various decisions. Sequences of decisions and events are diagrammed as successive branches on a tree graph (see figure 1). 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.

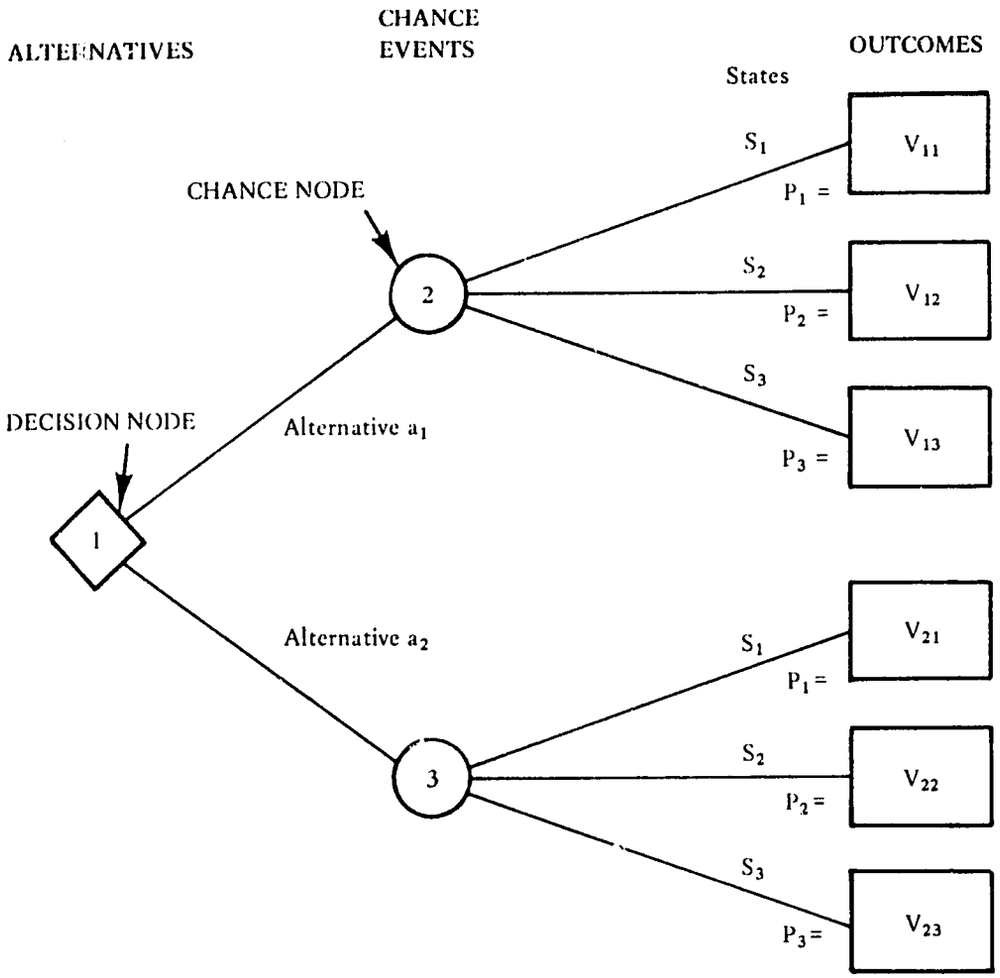
3. **Determine the event probabilities necessary for analyzing the decision situation.**
   - 3.1 Estimate the probabilities for the occurrence of each event affecting the decision-event stages (see Subjective Probability Assessment, SPA, page 137).
   - 3.2 Write the probabilities on the branches corresponding 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

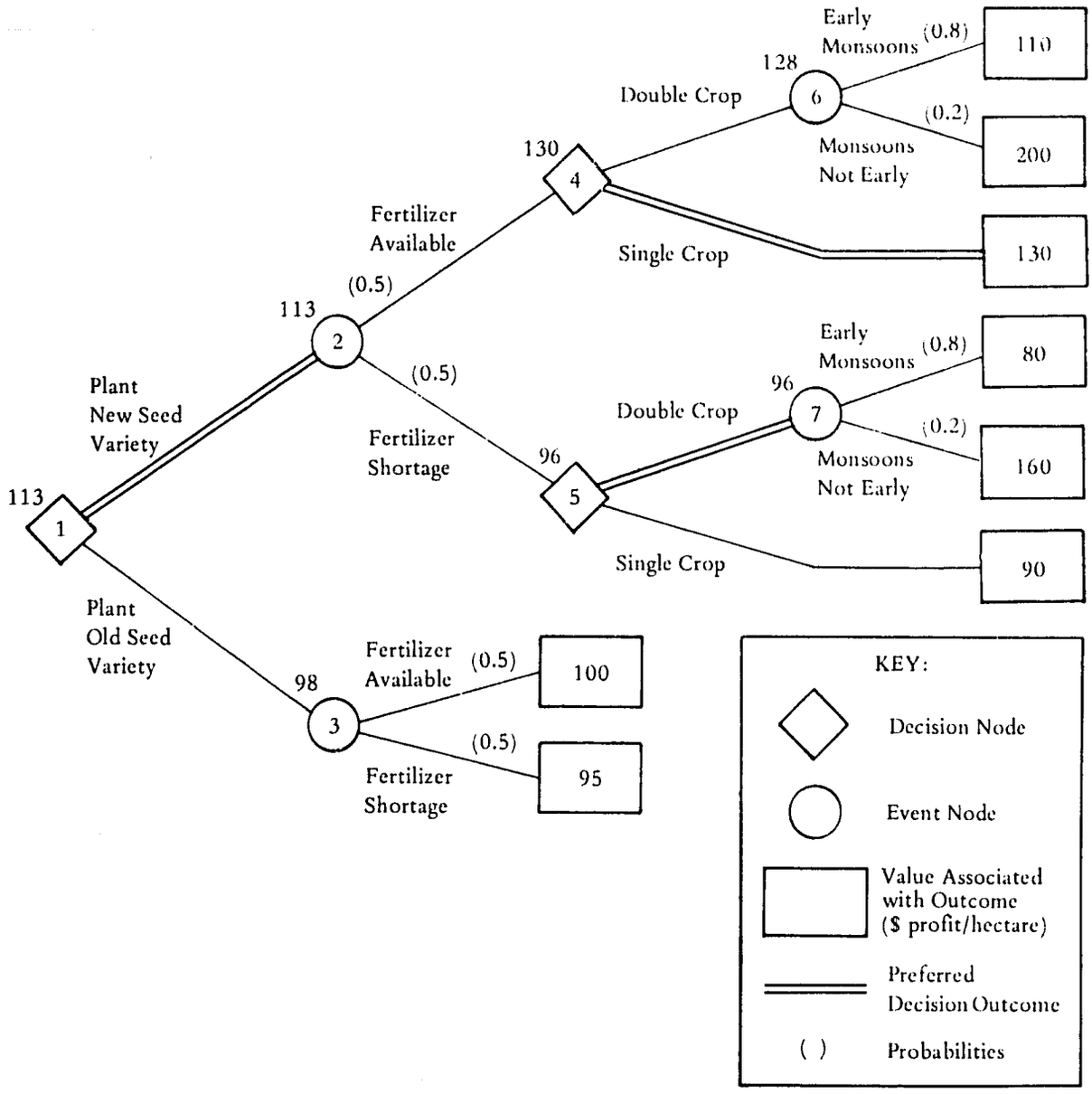
| | Chance Events / States of Nature | | |
|---|---|---|---|
| | $S_1$ | $S_2$ | $S_3$ |
| Probability | $P_1 =$ | $P_2 =$ | $P_3 =$ |
| Alternative $a_1$ | $V_{11}$ | $V_{12}$ | $V_{13}$ |
| Alternative $a_2$ | $V_{21}$ | $V_{22}$ | $V_{23}$ |

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.

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# 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 multi-disciplinary 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 recom-

mended 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%[1] |
| 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.
[1] 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.

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# 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, DLF, 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 (PTS).

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, PPM).

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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