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Each of the tools discussed in Chapter 4 provides a different method for the project planner to describe variables and relationships in a system, to identify problems, and to prescribe solutions. The System Definition Matrix is a prescriptive model for identifying the conditions and details that need to be specified in developing a plan or design. It is also a descriptive model for understanding and specifying the components of a system in order to communicate and to help understand the system's function in its environment. Three methods (Tree Diagrams, Oval Diagramming, and Interaction Matrix Diagrmamming) present approaches to structuring complex relationships with visual representations. Tree Diagrams illustrate a set of complex relationships through the use of a model which fits the relationships into a hierarchy of related factors. Oval Diagramming presents a model which identifies system variables in ovals and connects the variables together with arrows to diagram complex causes and effects. Interaction Matrix Diagramming provides a technique for first identifying the members of a set of elements, e.g., the objectives for a project, and then systematically examining all the possible interactions among members of the set.

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IV
Describing Complex Relationships

System Definition Matrix
Tree Diagrams
Oval Diagramming
Interaction Matrix Diagramming

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

Contents

Illustrations . . . vii
Foreword . . . xi
Preface . . . xiii
Acknowledgments . . . xv
Tool Abbreviations . . . xvii
Introduction . . . xix

I GENERATING IDEAS

Brainstorming . . . 3
Synectics . . . 6
Morphological Analysis . . . 10
Nominal Group Technique . . . 14
Questionnaires . . . 19
Interviews . . . 23

II ASSESSING QUALITATIVE FACTORS

Rating Scales . . . 29
Multiple Criteria Utility Assessment . . . 32
Surveys . . . 36
Organizational Climate Analysis . . . 40

III DEFINING OBJECTIVES

Function Expansion . . . 45
Objective Trees . . . 49
Intent Structures . . . 55

IV DESCRIBING COMPLEX RELATIONSHIPS

System Definition Matrix . . . 67
Tree Diagrams . . . 74
Oval Diagramming . . . 81
Interaction Matrix Diagramming . . . 92

V ANALYZING COMPLEX PROCESSES

Flowcharts . . . 107
Decision Tables . . . 113
Computer Simulation Models . . . 120
Gaming . . . 124

VI ACCOUNTING FOR ALTERNATIVE OUTCOMES

Histograms . . . 131
Subjective Probability Assessment . . . 137
Decision Trees . . . 141
Contingency Analysis . . . 147

VII FORECAST AND PREDICTION

Exponential Smoothing Forecasts 155
Regression Forecasting 160
Scenarios 164
Delphi 168

VIII ANALYZING PROJECTS

Cash Flow Analysis 177
Discounting 184
Net Present Worth 188
Benefit-Cost Ratio 194
Internal Rate of Return 200
Impact-Incidence Matrix 207
Cost-Benefit Analysis 212
Cost-Effectiveness Analysis 219

IX PLANNING, CONTROLLING, AND EVALUATING PROJECTS

Program Planning Method 227
IDEALS Strategy 231
Planning, Programming, and Budgeting 236
Critical Path Method 241
Gantt Charts 252
Logical Framework 260

List of Cross-References 265
Glossary 267

List of Figures

Morphological Analysis
1. Attributes for an Energy Policy Situation 11
2. One Combination of Attributes Indicated in a Morphological Chart 12

Nominal Group Technique
1. Index Card Illustrating Rank-Order Voting Process 17

Rating Scales
1. Examples of Rating Scales Applied to Discrimination Among Three Projects 30

Multiple Criteria Utility Assessment
1. Utility Matrix for Evaluating Alternatives 32
2. Utility Function 33
3. Utility Functions for Evaluating Farmer Contact Strategies 34
4. Utility Matrix for Ministry of Agriculture Farmer Contact Strategy 35

Organizational Climate Analysis
1. Dimensions to Be Considered in Climate Assessment 41

Function Expansion
1. Function Hierarchy for Employment System 46
2. Forecasting the Function Expansion on the Most Regularly Occurring Concern 48
3. Function Expansion List for Employment Service 48

Objective Trees
1. An Example of a Partial Objective Tree Developed for a Hydro-Electric Project 50
2. Examples of Quantitative, Binary-Event and Qualitative Objectives Classified by Methods of Measurement 51
3. An Example of an Objective Tree Developed for a Hydro-Electric Project 53

Intent Structures
1. Format for Intent Structure 56
2. Logic Elements for Intent Structures 56
3. Use of AND Logic Element 58
4. Use of OR Logic Element 58
5. Use of the Exclusive OR (XOR) Logic Element 59
6. Intent Structure for Hydro-Electric Reservoir Project 62

System Definition Matrix
1. System Definition Matrix Format: A Hospital System 68
2. System Definition Matrix in List Format for Alcoholics Treatment Center 70

Tree Diagrams
1. Tree Graph Form 75
2. Fundamentals of Tree Diagram Construction 76
3. Relevance Tree Examples for Family Planning Program 77
4. Tree Diagram to Start Oval Diagram for Nomad Pastoralism Eco-System 79

Oval Diagramming
1. Oval Diagram for Nomad Pastoralism Eco-System 82
2. Multiple Causal Relationships 84
3. Types of Interaction Between Two Variables, A and B 84
4. Illustration of Threshold Relationships 85
5. Illustration of Irreversible Effects 85
6. Summary of Symbols and Notation for Oval Diagramming 87
7. Influence Tree Diagram Prepared to Start Oval Diagram of Nomad Pastoralism Eco-System 88
8. The Initial Steps in Constructing an Oval Diagram from a Tree Diagram 89
9. Oval Diagram Depicting Causal Loops in Nomad Pastoralism Eco-System 90

Interaction Matrix Diagramming
1. Interaction Matrix Diagram Derived from Oval Diagram of Nomad Pastoralism Relationships 93
2. Properties of Relationships 94
3. Examining an Interaction Matrix for Intransitive Relationships 97
4. Reduced Cross-Interaction Matrix for Environmental Assessment 98
5. Oval Diagram for Nomad Pastoralism Eco-System 100
6. Revised Interaction Matrix Diagram Showing Influences on Interventions in System 101
7. Tree Diagram Clarifying the Influence Relationships in the Interaction Matrix Diagram Example 102

Flowcharts
1. A Flowchart for the Task of Constructing a Flowchart 108
2. Examples of Decision Points for Flowcharting 110
3. Behavioral Model of Development Administration 111

Decision Tables
1. Decision Table Used by Donor Agency for Depositing Loan Funds into Special Program Account 114
2. Flowchart of Interpolation Procedure to Determine Internal Rate of Return 116
3. Mixed Entry Decision Table for Determining Internal Rate of Return by Interpolation 118

Histograms
1. Sample Histogram for Raw Data 132
2. Histogram for Clustered Data 133
3. Mean and Standard Deviation of Raw Data Values 135
4. Mean of Grouped Data 136
5. Standard Deviation of Grouped Data 136

Subjective Probability Assessment
1. A Probability Density Function 138
2. A Probability Density Function for the Tourist Industry of Temasek 140

Decision Trees
1. Decision Tree for Farmer with Choice of New Seed Variety and Double Cropping 142
2. The Decision Tree Representation of a Decision Under Risk 144
3. Analyzing the Decision Tree to Determine Maximum Expected Profit/Hectare 145

Contingency Analysis
1. Contingency Table with Qualitative Evaluation of Plan Performance 148
2. Contingency Table for Agricultural Strategy Planning 150

Exponential Smoothing Forecasts
1. Plots of Past Data 156
2. Work Sheet for Exponential Smoothing 159

Regression Forecasting
1. Graph of Regression Line 161
2. Regression Computation 163

Scenarios
1. A Standard Format for a Scenario 166

Delphi
1. Schedule for Delphi 170
2. Frequency Distribution of Estimates of Minimum Wage 171

Cash Flow Analysis
1. Graphic Illustration of Cash Flows for a Project 178
2. Small Farmer Tractor Utilization: Purchase Option 180
3. Computing the Net Incremental Benefit or Cash Flow Resulting from a Project 182

Discounting
1. Computing the Present Worth of a Series of Nonuniform Payments 186

Net Present Worth
1. Computing the Net Present Worth: Small Farmer Tractor Utilization—Purchase Option 190
2. Cash Flow Analysis: Small Farmer Tractor Utilization—Rental Option 191
3. Net Present Worth Calculated from Discounted Cash Flow for Tractor Utilization—Rental Option 192

Benefit-Cost Ratio
1. Computing the Benefit-Cost Ratio for Small Farmer Tractor Utilization: Purchase Option 196
2. Cash Flow Analysis: Small Farmer Tractor Utilization—Tractor Cooperative Option 197
3. Computing Benefit-Cost Ratios for Small Farmer Tractor Utilization: Cooperation Option 198

Internal Rate of Return
1. Flowchart of Interpolation Procedure to Determine Internal Rate of Return . . . 202
2. The Annual and Total Cash Flows for the Small Farmer Tractor Utilization Options . . . 203
3. Computation of the Internal Rate of Return for the Small Farmer Tractor Options . . . 204

Impact-Incidence Matrix
1. Impact-Incidence Matrix for Cost-Benefit Analysis . . . 208
2. Impact-Incidence Matrix Example: Tractor Training Program . . . 210

Cost-Benefit Analysis
1. Summary of Assumptions for Small Farmer Tractor Utilization . . . 216
2. Comparing the Small Farmer Tractor Utilization Options . . . 216

Cost-Effectiveness Analysis
1. Reliability and Acceptance Rates for Alternative Means of Birth Control . . . 222
2. Cost Analysis of Alternative Means of Birth Control . . . 222
3. Cost-Effectiveness of Alternative Birth Control Means . . . 223

IDEALS Strategy
1. Function Hierarchy for IDEALS Strategy . . . 232
2. Identifying Measures of Effectiveness, Regularities, and Ideal Concepts . . . 233
3. Preliminary System Definition Matrix for a Job Information System . . . 234

Planning, Programming, and Budgeting
1. Goals and Programs for the Federal Economic Development Administration . . . 238
2. Analysis of Program Alternatives . . . 239

Critical Path Method
1. Project Network for the Activities Necessary to Arrange a Seminar . . . 242
2. Activity Card with Location of Notations . . . 244
3. Table Format for Computation of Critical Path . . . 245
4. Immediate Precedessor and Successor Relationships . . . 246
5. Completed Activity Table for Activities to Arrange a Seminar . . . 249
6. Completed Project Network Showing Critical Path and Milestones . . . 250

Gantt Charts
1. A Gantt Chart Example: Planning and Conducting a Survey . . . 253
2. Critical Path Network for Survey Project . . . 256
3. Activity Table for Survey Project . . . 257
4. Gantt Chart for Survey Example after Adjustments for Limited Manpower . . . 258

Logical Framework
1. The "Logical Framework" . . . 261
2. An Example of a Logical Framework . . . 263

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

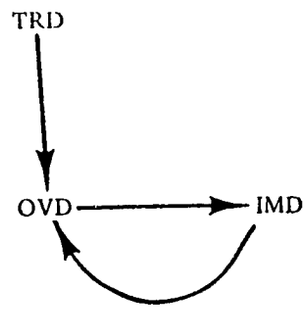
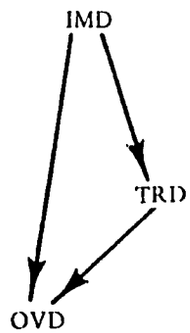
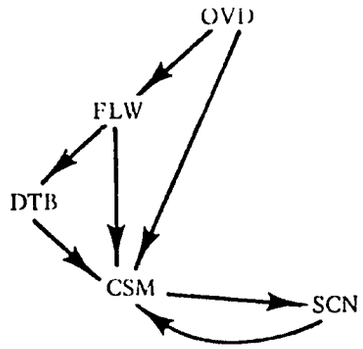


FIGURE 1b



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



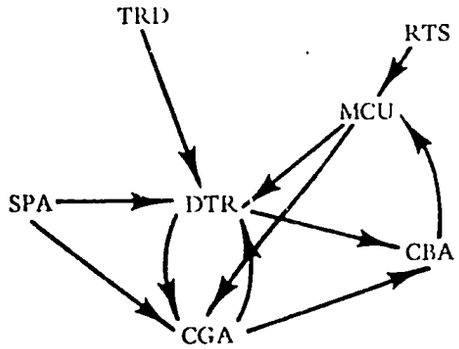
GENERATING AND ANALYZING ALTERNATIVE PLANS OF ACTION

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

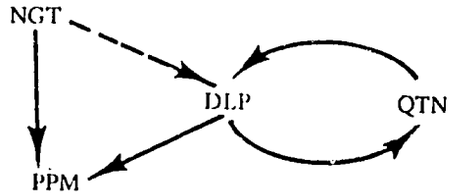
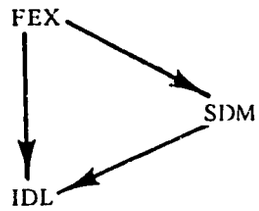


FIGURE 5



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.

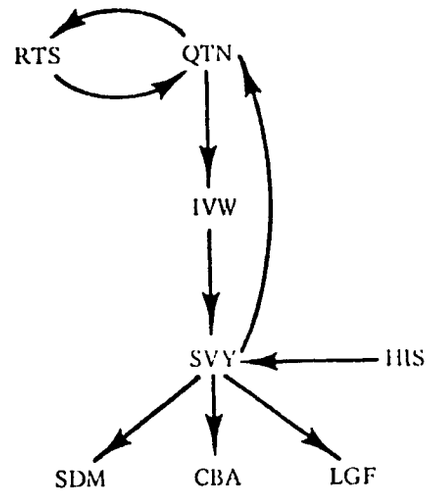
Focusing on function rather than on problems gets people involved in a constructive assessment of what should be, rather than what's wrong and who's to blame. There are sound arguments for both approaches. The IDEALS Strategy often comes under attack because its emphasis on normative specification may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

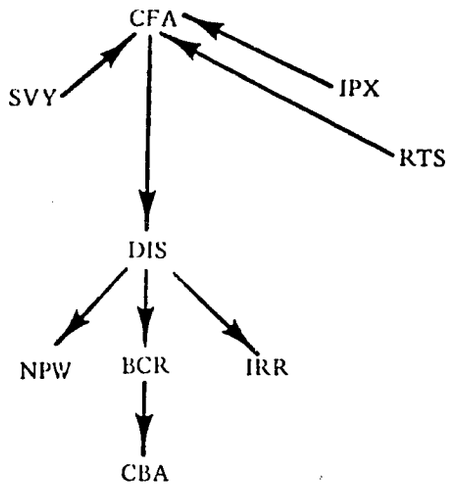
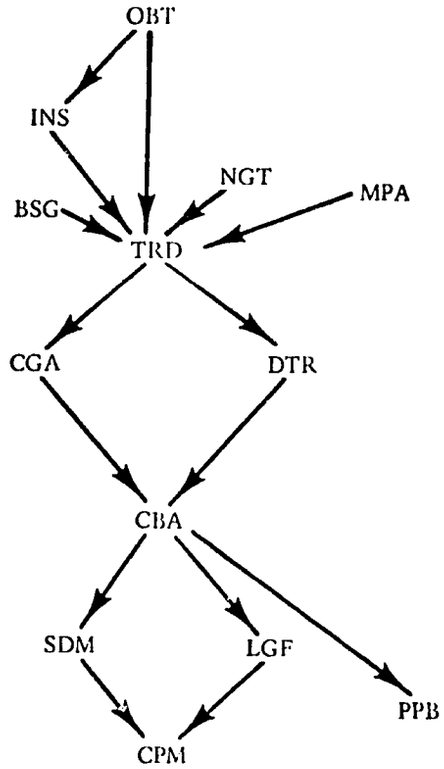


FIGURE 8



THE "CONVENTIONAL" SYSTEMS APPROACH

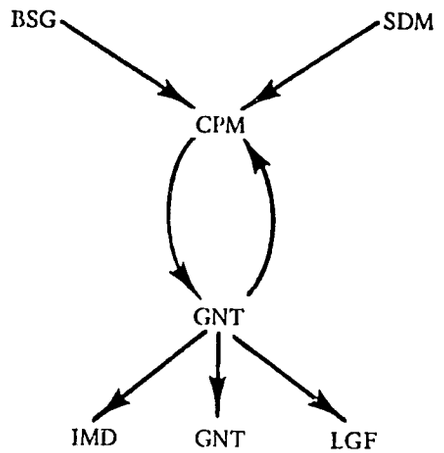
Systems analysis begins with identifying objectives, specifying alternative means, specifying the criteria for selecting among the alternatives, and then synthesizing a system or plan from the choices. A sequence of techniques for applying the systems analysis strategy begins with Objective Trees (OBT,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

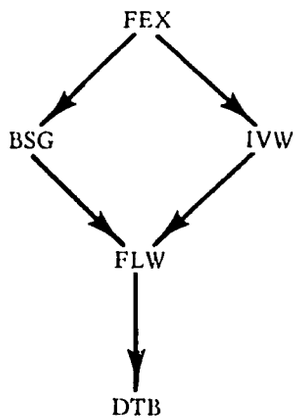
Framework may also be used to sharpen the identification of objectively identifiable indicators of progress. These milestones are shown as vertical lines on specific dates of the Gantt Chart and written on the Critical Path Method network at the appropriate nodes.

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

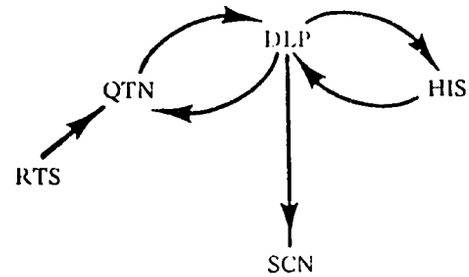


The results of this analysis are presented in the form of flowcharts (FLW, page 107) or decision tables (DTB, page 113). The flowchart uses different symbols to display and analyze complex processes. The decision table presents the decision as a preprogrammed process by specifying the conditions which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

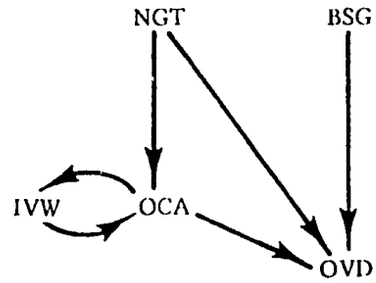


The Delphi technique (DLP, page 168) begins by directing questionnaires to a selected group of prognosticators. The results of each round are summarized for the Delphi group, often in the form of a histogram which aggregates the individual judgments. Rating scales attempt to quantify priorities and opinions.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

System Definition Matrix

PREREQUISITE TOOLS

None.

USAGE

PURPOSE

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

USES

The System Definition Matrix may be used as:

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

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

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

KEY DEFINITIONS

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

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

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

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

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

SHORT DESCRIPTION

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

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

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

ADVANTAGES

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

FIGURE 1
System Definition Matrix Format: A Hospital System

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

*See Flowcharts, FLW, page 107.

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

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

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

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

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

LIMITATIONS

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

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

REQUIRED RESOURCES

LEVEL OF EFFORT

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

SKILL LEVEL

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

TIME REQUIRED

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

DESCRIPTION OF TOOL

SUPPLEMENTAL DEFINITIONS

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

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

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

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

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

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

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

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

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

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

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

FIGURE 2

System Definition Matrix in List Format for Alcoholics Treatment Center

Function

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

Input

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

Output

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

Sequence

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

FIGURE 2
Continued

Environment

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

Physical Catalysts

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

Human Agents

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

Information Catalysts

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

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

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

REQUIRED INPUTS

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

TOOL OUTPUT

The output is the System Definition Matrix with a partial or complete specification of elements and dimensions. The System Definition Matrix may then be used in other tools, such as Scenarios (SCN, page 164), Gaming (GAM, page 124), Cost Benefit Analysis (CBA, page 212), and Computer Simulation Models (CSM, page 120). The IDEALS Strategy (IDL, page 231) uses the System Definition Matrix as a format to specify results.

An alternative breakdown of system elements which describes public service agencies may be used to avoid the input → sequence → output terminology. The terminology avoids the jargon used for the System Definition Matrix elements. The list and questions which may be associated with each element (and the corresponding matrix element) are:

Purposes (function): Why? What is the mission?
Background (information): What do I know? What are their previous states?
Clients (inputs): Who? What are their present states?
Results (outputs): What are the changed states of clients?
Method (sequence): What ways? How to get results?
Setting (environment): What is political or social atmosphere?
People (human agents): Who are the doers?
Facilities (physical catalysts): What is needed to do it?
Dollars (inputs): What are the costs?

IMPORTANT ASSUMPTIONS

The development of a System Definition Matrix assumes that a system can be broken down morphologically into distinct components. The distinction between inputs, outputs, and catalysts may often be blurred. This is particularly true if the same set of components is involved in quite different functions. For example, hospital staff are human agents in a patient treatment system and inputs to the hospital management control system.

METHOD OF USE

GENERAL PROCEDURE

The development of a System Definition Matrix may be a creative as well as an analytical exercise. Consequently, involving knowledgeable staff is productive. Nominal Group Technique (NGT, page 14) or brainstorming (BSG, page 3) may be used to discover entries.

The procedure begins with function specification, but may repeat and backtrack as necessary.

1. Specify the function.
   1.1 Discuss the system to determine its function (a function expansion, FEX, page 45, may be used).
   1.2 Proceed to the fundamental specification of other elements before specifying the other four dimensions of the system function.

2. Identify inputs and other system elements.
   2.1 Try to complete all the entries for the fundamental dimension column of the matrix.
   2.2 If a list format is being used, skip dimensions of rate, control, etc. and return to them after other elements have been specified. An alcohol workshop identified the inputs for the treatment system as "clients with a drinking problem" (see figure 2).

3. Complete the dimensions for each element.
   3.1 Complete the rate, control, and state dimensions for all elements except function. It may not be possible to specify all cells in the matrix, and they may be temporarily left blank.
   3.2 If an element of the system does not include a particular dimension, indicate "none required" or "not applicable, N.A." in the matrix to show that the possibility has not been overlooked, e.g., there may be no control dimension for system inputs. Figure 2 contains a description of a partially specified alcoholic treatment system.

4. Complete system function dimension.
   4.1 Complete the dimension specifications of system function if possible.
   4.2 In this row, indicate foreseeable changes to the system function.
   4.3 Note interfaces with other systems.

5. **Complete interface dimensions.**
   Where appropriate, complete the interface column of the System Definition Matrix for the eight elements. For example, the alcoholic treatment system inputs (clients) may interface with the output of public service agencies (e.g., the police).

6. **Check the matrix for completeness.**
   Fill blank cells as additional information is gathered.

7. **Repeat process to desired level of detail.**
   Repeat the process for particular cells. For example, the control dimension of system output may suggest a subsystem whose function, inputs, outputs, etc. may be specified in a separate matrix. In this way, a very detailed morphological breakdown of a system and its subsystems may be modeled.

EXAMPLE

Figure 2 presents a partially specified System Definition Matrix (in list format) for an alcoholic treatment system.

THEORY

The theoretical basis for the System Definition Matrix is founded in the theory of systems. In defining what is meant by a system, different terminology and levels of detail may be used, but essentially a descriptive model is developed.

The System Definition Matrix imposes a morphological structure on a conceptual model to produce a description of the system components. This may differ from similar systems descriptions in the explicit treatment of system functions and dimensions of rate and future state. Nadler (1970) is responsible for the System Definition Matrix format, particularly the emphasis on function and the explicit treatment of catalysts.

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Tree Diagrams

PREREQUISITE TOOLS

None.

USAGE

PURPOSE

A tree diagram illustrates a set of complex relationships by fitting them into a *hierarchy* of related factors.

USES

Tree diagrams are used to:

1) Describe the relationships among objectives of a project (see Objective Trees, OBT, page 49).

2) Describe the relationships among alternatives, as in *means-ends analysis* or Decision Trees (DTR, page 141).

3) Clarify sequences of relationships in Interaction Matrix Diagrams (IMD, page 92).

4) Develop relationships among variables of a system as in *influence trees* which may then be redrawn as oval diagrams (OVD, page 81).

5) Provide a measure of the degree of relatedness among different sets of factors, as in *relevance trees.*

KEY DEFINITIONS

1) A *hierarchy* is an ordered structure illustrating which factors are subordinate to others.

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

3) An *influence tree* diagrams the variables which influence other variables which are higher in the tree.

4) A *relevance tree* diagrams the relationships among different sets of factors at each level of a hierarchy.

5) A *model* is a representation or an imaginary entity that contains information in a certain predefined form and has specified rules for interpretation (Thesen, 1973).

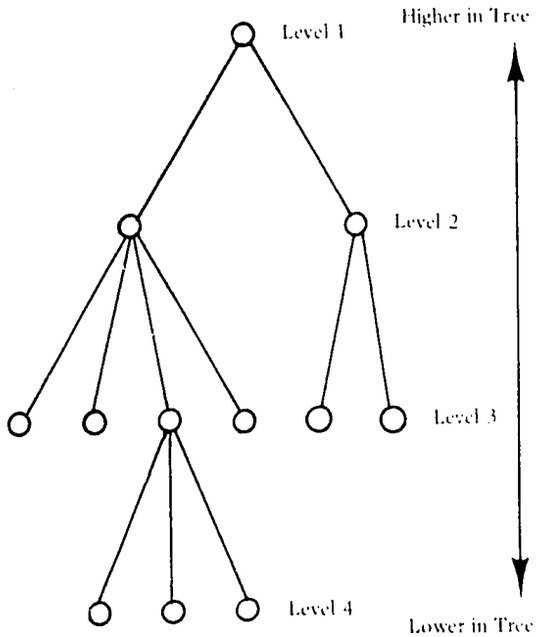
6) A *tree graph* is a set of linked elements where only one link exists between any two factors (see figure 1).

7) A *branching rule* governs the construction of relationships in a tree diagram (see figure 2).

SHORT DESCRIPTION

A tree diagram is a *model* which describes a set of relationships by using a *tree graph* (see figure 1). The branching points are factors related to each other according to a *branching rule.* The types of factors shown and the branching rule used are determined by the purpose of the diagram (see figure 2). For example, project objectives are modeled as objective trees (see OBT, page 49) to describe subordinate relationships. More information may be added to the diagram to facilitate analysis and to clarify relationships, e.g., to identify the levels of a relevance tree or to assign weights to alternative outcomes.

FIGURE 1
Tree Graph Form



KEY:
O Factors (variables, objectives, alternatives, etc.)
— Relationships (causal, influence, subordinate, etc.)

ADVANTAGES

A tree diagram is constructed by doing a logical breakdown of complex relationships. The branches of the diagram reduce a set of relationships to its essential components to expedite analysis.

LIMITATIONS

A tree diagram implies a level of determinacy which may be unwarranted. All elements of the diagram can seldom be determined in advance—a fact which must not be overlooked during subsequent analysis.

REQUIRED RESOURCES

SKILL LEVEL

Tree diagramming can be learned rapidly with practice. Because other techniques may be required to make maximum use of the tree diagram, the skill level required depends on the purpose.

TIME REQUIRED

Tree diagrams may be drawn rapidly as the development is usually quite logical. Some time is necessary for information-gathering and analysis, depending on the particular type of tree diagram.

DESCRIPTION OF TOOL

SUPPLEMENTAL DEFINITIONS

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

2) A *component* of a system is an entity which may be elemental or it may be a subsystem having distinct components.

3) A *stopping rule* determines when any branch of the tree diagram should end.

4) An *influence* relationship occurs when one variable's change in value influences change in another variable, e.g., the ACCEPTANCE OF INNOVATIONS is influenced by the YIELD FROM CROPS.

5) There is a *producer-product* relationship when one variable is a product of the other (e.g., RANGE FEED is a product of AVAILABLE PASTURE).

REQUIRED INPUTS

The purpose of the tree diagram should be clearly established prior to its construction to determine the types of factors to be shown and the relationships to be described. Some familiarity with the problem context is necessary in order to be able to depict relationships and identify factors

TOOL OUTPUT

Tree diagramming results in a description of a complex set of relationships. Simply developing the tree diagram may be sufficient for gaining an understanding into the structure of relationships and the span of relevance of various factors.

However, tree diagrams are usually the intermediate output of a more detailed analysis, e.g., influence diagrams may be converted into oval diagrams (OVD, page 81), and additional information can be gathered to complete a decision tree (DTR, page 141).

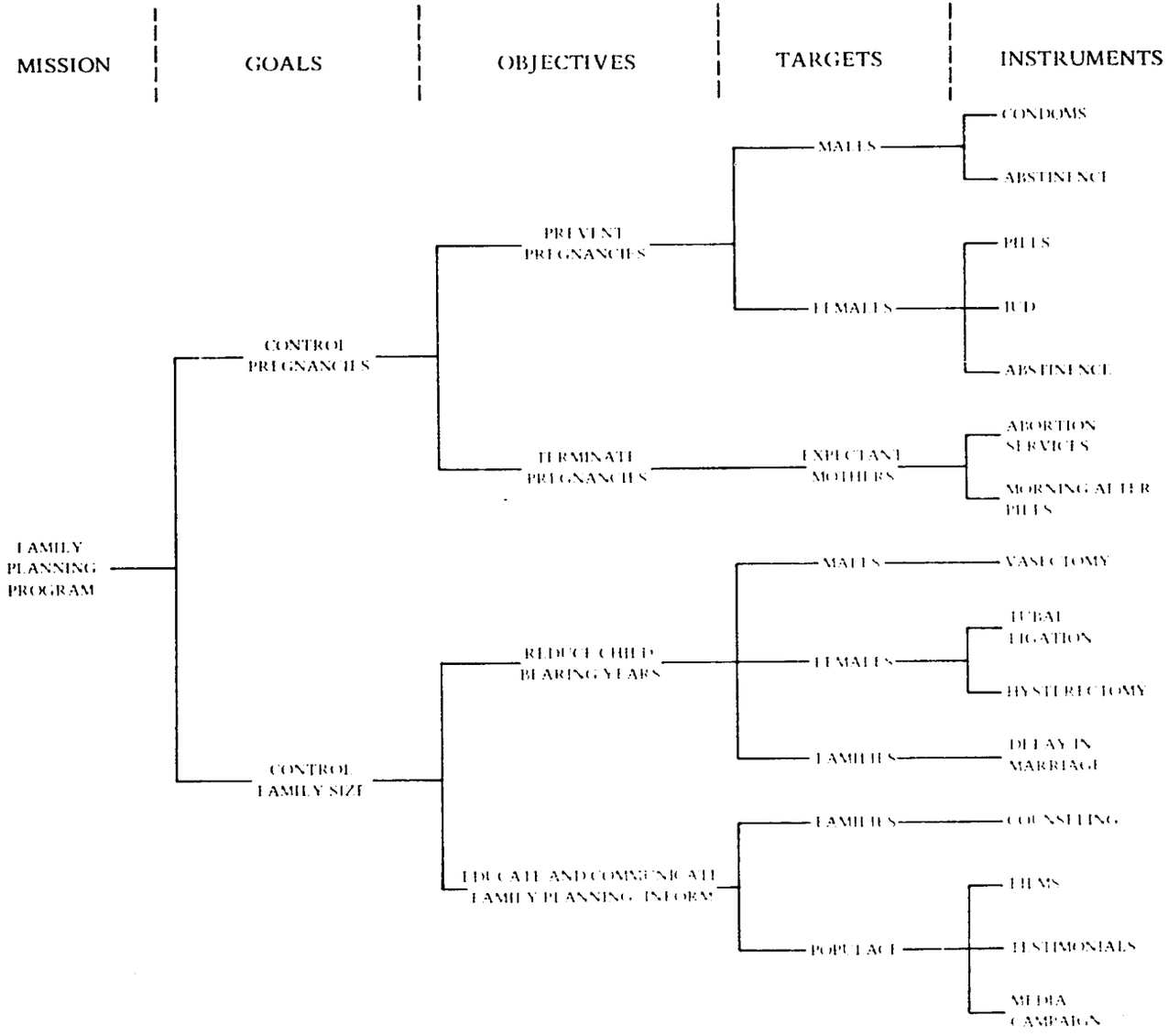
IMPORTANT ASSUMPTIONS

A hierarchical relationship is assumed to exist among the elements of a tree diagram. For example, if the set of complex relationships describes a *system*, then the tree diagram decomposes the system into *components*, each of

FIGURE 2
Fundamentals of Tree Diagram Construction

TREE DIAGRAM TYPE	FACTORS DIAGRAMMED	BRANCHING RULE
INFLUENCE TREE	SYSTEM VARIABLES	IDENTIFY THE VARIABLES WHICH INFLUENCE THE VARIABLE
RELEVANCE TREE	SETS OF PROGRAM FACTORS	IDENTIFY THE FACTORS ASSOCIATED WITH EACH FACTOR IN NEXT HIGHEST LEVEL OF THE TREE
OBJECTIVE TREE	OBJECTIVES	IDENTIFY THE OBJECTIVES NECESSARY TO ACHIEVE EACH HIGHER LEVEL OBJECTIVE
MEANS-ENDS TREE	ENDS AND ALTERNATIVE ACTIONS	WORK DOWN THE TREE: HOW IS THIS ACTION TO BE ACHIEVED? WORK UP THE TREE: HOW IS THIS ACTION TO BE UNDERTAKEN?
DECISION TREE	ALTERNATIVE ACTIONS AND EVENTS WHICH AFFECT OUTCOME OF ACTIONS	IDENTIFY ALTERNATIVE ACTIONS; IDENTIFY EVENTS. REPEAT UNTIL ALTERNATIVES ARE EXHAUSTED.

FIGURE 3
Relevance Tree Examples for Family Planning Program



which may be further broken into components, etc. Or every system may be subdivided into subsystems, and consequently, every system is a component of some larger system.

METHOD OF USE

GENERAL PROCEDURE

1. Determine the type of factors to be shown on the diagram.
2. Determine the appropriate branching rule.
3. Determine the starting factor of the tree.
4. Identify related factors using the branching rule and show them as branches stemming from the starting factor.
5. Determine the appropriate stopping rule.
6. Repeat step 4 for each newly identified factor unless the stopping rule applies.
7. Review the tree for consistency of rule application.
8. Add any information necessary for analysis.

EXAMPLES

Two examples will be used to illustrate the tree diagramming technique. Other applications are found in the Objective Trees (OBT, page 49), Decision Trees (DTR, page 141), and Interaction Matrix Diagrams (IMD, page 92).

Relevance Tree Diagram

A relevance tree can be used to describe the relationships of different elements in a family planning program (see figure 3).

The starting variable is a simple identification of the mission of the program. The branching rule is in four parts:

1) What are the goals which correspond to this mission?

2) What are the objectives which correspond to each goal?

3) What are the targets for each objective?

4) What are the instruments relevant to each target for accomplishing the objective?

Identifying the instruments completes the tree and thus decomposes a complex program into its various elements.

Influence Tree Diagram

Much of the success of this technique depends on the art and expertise of the analyst. The example that follows examines some of the relationships which describe the nomad pastoralism eco-system.

The following excerpts from a description of an M.I.T. study describe the factors affecting the conditions in the Sahel:

> In the Sahel live the nomads, who follow the rains to the north every year and retreat to the south in the dry season. Their numbers have traditionally been limited partially by the number of cows and goats the land was able to support, and by the distance between water holes. Western agencies working in the area during the past decade made the obvious but ill advised move of digging wells throughout the grazing commons. The numbers of cattle, and people, grew proportionately, using much of the grazing land for the greater part of the year instead of seasonally, allowing the land no time to recover. The herds moving southward during the dry season have been forced to travel over land that has already been overgrazed and, finding water but no forage, have literally starved at the water holes. . . .
>
> It is this widespread overuse that is preventing the land from recovering even when rain does fall. Instead of being absorbed, the rain falling on the vegetation stripped ground merely washes off the topsoil. The cycle—overgrazing, wind, rain—is causing the desertification of much of the land.*

The variables and relationships which describe the influences on livestock population are shown in figure 4. The starting variable selected was HERD SIZE, an aggregated representation of all domesticated grazing animals in the Sahelian region. NOMAD POPULATION is an equally appropriate starting variable, but the tone of the excerpts suggests that the relationships between animal populations and range conditions are central to describing the eco-system.

The following branching rule was applied to each newly identified variable:

Identify the variables which influence this variable.

Other relationships can be diagrammed by inserting "produces" or "causes this variable to change" in the branching rule. The rule specifies the relationship, whether it is cause-effect, *producer-product*, or simply the influence of one variable on another.

If the branching rule were changed to:

Identify variables which are influenced by this variable,

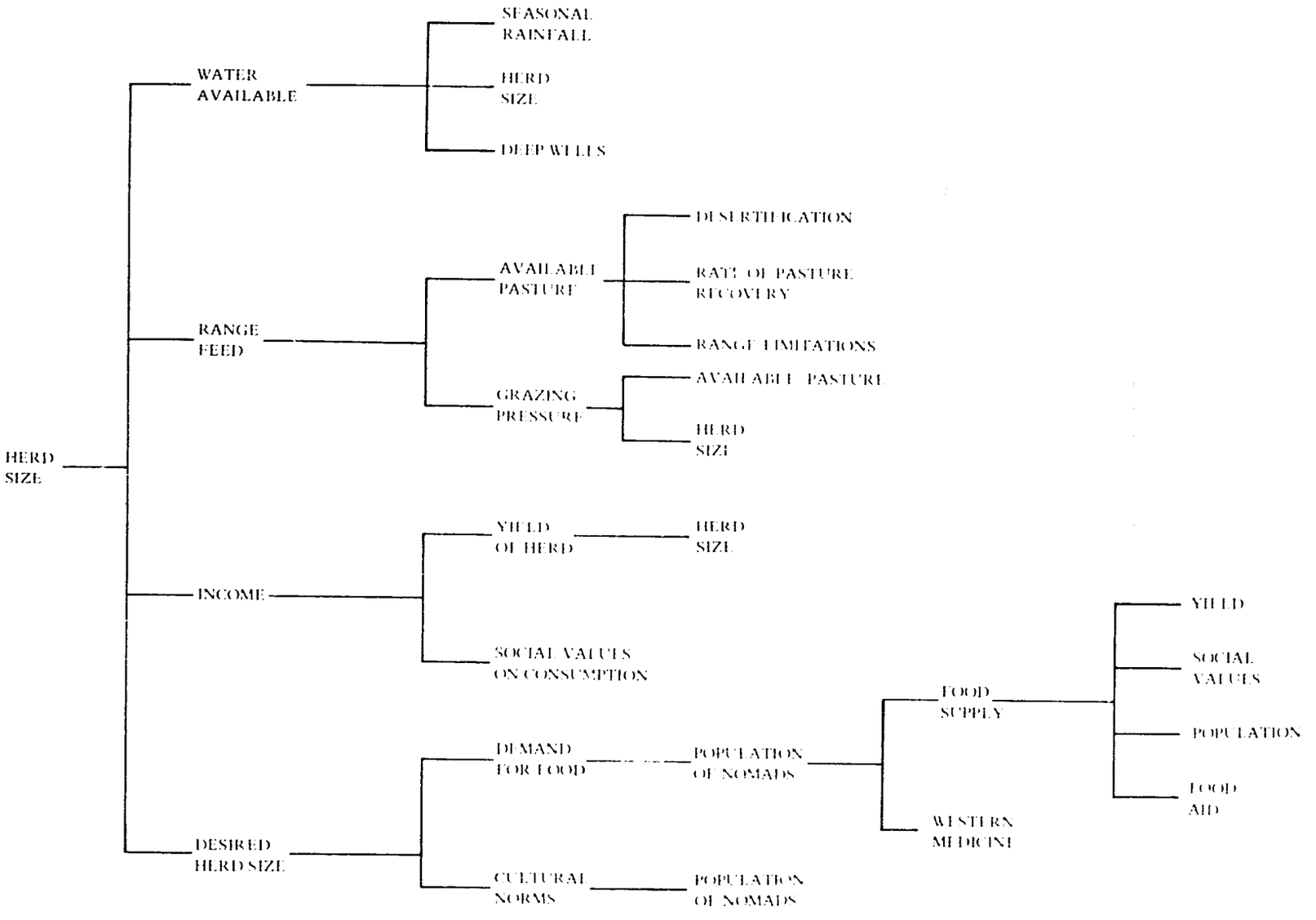
the direction of influence implied by the tree structure would be reversed. Generally, it is easier to start with observed effects and attempt to identify causes.

Two stopping rules were used to terminate the branching process:

1) Stop with any variable which is already shown on the diagram, or

*S.J.N., " 'Tragedy of the Commons' in Africa," *Technology Review* (October-November, 1974), pp. 73-74.

FIGURE 4
Influence Tree Diagram for Nomad Pastoralism Eco-System



2) Stop with any variable which is considered outside the purpose of the system, and which is not likely to be influenced by any other factor previously identified.

Rule 2 applied for variables like SEASONAL RAINFALL and SOCIAL VALUE ON CONSUMPTION (see fig. 4). Assuming that the eco-system functions to sustain life on the Sahel, these variables are considered outside the influence of factors within the system.

Rule 1 applied several times (e.g., HERD SIZE) and was employed to avoid redundant branching. When numerous branches terminate with the same variable, an oval diagram is a more economical form of representation for the complex relationships. This example is continued in the description of the oval diagramming technique (OVD, page 81).

THEORY

Tree diagrams are rooted in graph theory and the representation of hierarchical relationships (Warfield, 1973). The adoption of tree graphs for the tree diagramming technique relates more closely to systems theory than to mathematical topology.

Warfield (1974) has described the structural representations of complexity which emphasize the correspondence between a matrix and a graph of relationships. A tree diagram may be used to trace the linkages in an interaction matrix diagram (IMD, page 92) in order to clarify the interactions.

The decomposition of a set of complex relationships by techniques, which Harrison (1972) has called a process of "repeated-subdivision," assumes that the relationships form a hierarchy. The hierarchy may be a chain of cause-effect relationships, the nesting of one set of components within a larger component of a system, or the ordering of objectives from the specific to the general.

Relevance trees have been discussed extensively in the technological forecasting literature (Alderson and Sproull, 1972) as one of the more useful qualitative techniques. Attempts to quantify the order and strength of the relationships in a relevance tree (Fischer, 1970) are beyond the scope of this presentation.

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Oval Diagramming

PREREQUISITE TOOLS

Tree Diagrams (TRD, page 74).

USAGE

PURPOSE

Oval diagramming describes a problem as a set of complex relationships among system *variables* and variables in the system *environment*.

USES

An oval diagram provides an explicit statement of cause and effect relationships within a system and between the system and its environment. This diagram may be used to:

1) Examine the internal consistency of the analyst's conception of the complex relationships.

2) Communicate the analyst's understanding of causal relationships to others and to provide a graphic definition of the system.

3) Promote further study of hypothesized causes and observed effects, particularly when these represent problematic behavior.

4) Provide an input for techniques such as Computer Simulation Models (CSM, page 120) and Scenarios (SCN, page 164).

KEY DEFINITIONS

1) A *variable* is a factor used to describe a system which may change value as a function of time.

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

3) *Dynamic behavior* is a consequence of delayed interactions among system variables. The dynamic state of a system depends on the prior values of state variables.

SHORT DESCRIPTION

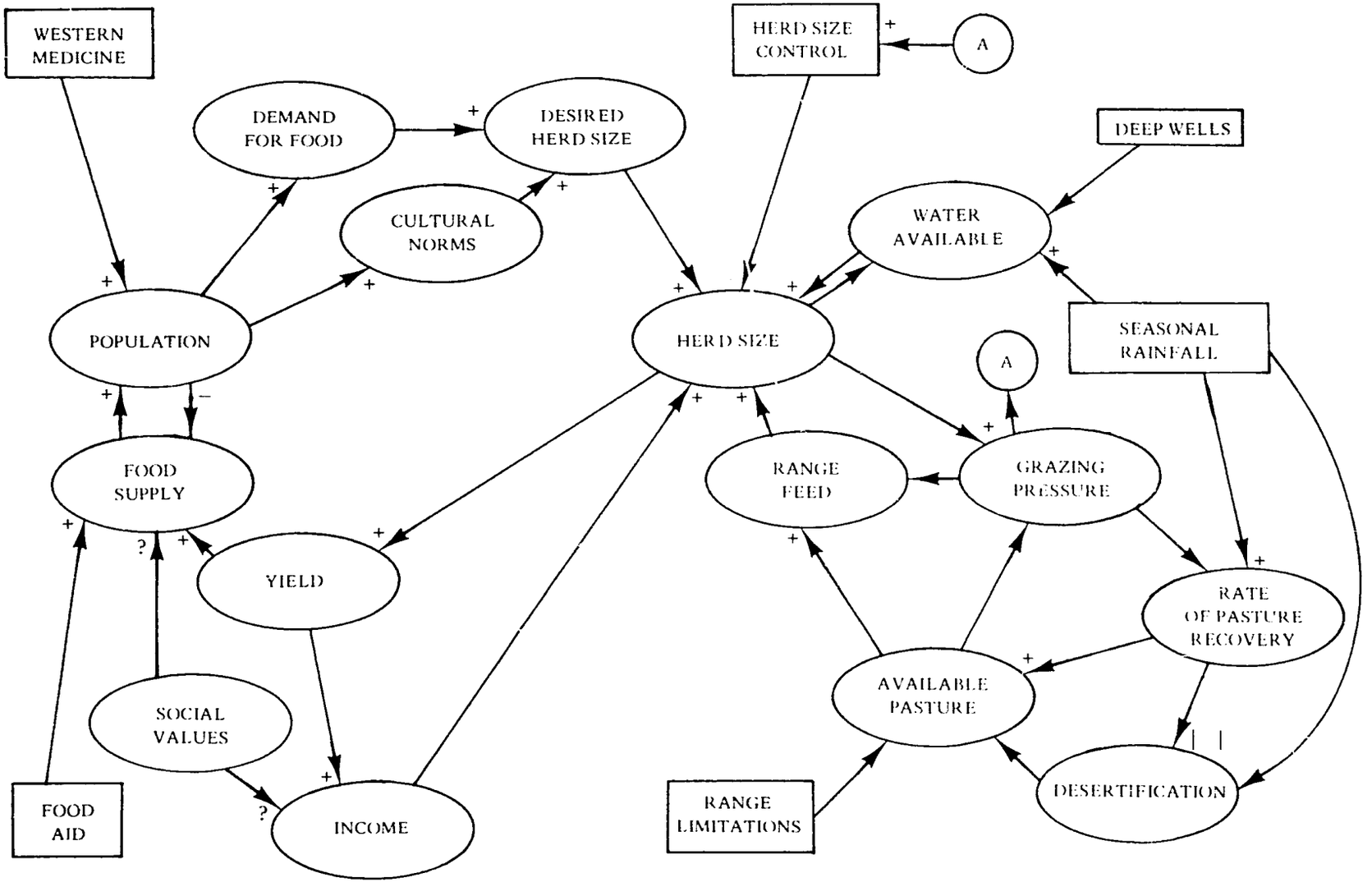
An oval diagram is a model which identifies system variables (in ovals) and the connecting arrows which link the variables together (see figure 1). The type of interaction is determined by considering the effect of a small change in one variable on the magnitude of another.

An oval diagram is constructed by drawing on the experiences, observations, and intuition of the analyst(s) in order to translate mental models into an explicit statement. This statement forms the framework for testing hypotheses, gathering additional data, or analyzing the system's *dynamic behavior*.

ADVANTAGES

1) In oval diagramming, complex causes and effects are seen as expanding sequences starting from a key variable.

FIGURE 1
Oval Diagram for Nomad Pastoralism Eco-System



2) The thought that goes into oval diagramming often uncovers relationships that may be the key to a further understanding of system behavior.

3) Oval diagrams facilitate communication between analysts and decision makers by highlighting undesirable effects and relationships that require careful attention.

4) By treating assumptions and hypotheses explicitly, oval diagrams may resolve discrepancies or deficiencies in the mental models used by decision makers.

5) The span of relevant factors is easily shown in the oval diagram so that changes in the problem scope can be accommodated by changing the diagram.

LIMITATIONS

1) Diagramming all conceivable interactions results in a complex and unwieldy diagram. On the other hand, highly aggregated models may lead to false inferences about system behavior (see DeNeufville and Stafford, 1969).

2) The validity of the oval diagram can only be inferred by relation to experience. Any hypothesized relationship may be proven false by a statistical analysis of data, but failure to do so does not validate the relationship. For example, it may be demonstrated that a relationship between NUMBER OF EXTENSION WORKERS and NUMBER OF FARMERS ENTERING A PROGRAM does *not* exist; however, no test will assure one that there is a causal relationship.

3) An oval diagram may be idiosyncratic because there is no unique representation of a complex set of relationships.

4) The selection of salient variables and relationships reflects the biases of the analyst, even though the diagrammer may attempt to incorporate shared values into the hypothesized relationships.

5) The oval diagram is a descriptive model only—the complex interaction of multiple variables and relationships can only be inferred. Other techniques are required to fully understand the behavior of the entire system (see Computer Simulation Models, CSM, page 120).

REQUIRED RESOURCES

LEVEL OF EFFORT

The level of effort required depends on the planned use for the tool.

1) If the oval diagram is a first step in complex modeling and systems analysis, then the effort will match the input requirements of the tool used in the next step.

2) If the tool output is used for communication, discussion, or training, then more effort may be spent on refining the final diagram.

3) If the tool is designed to facilitate understanding as an aid to decision making, or for clarifying issues, then more attention must be given to the development process and explicit treatment of assumptions and hypotheses.

SKILL LEVEL

The analyst must be able to see the problem and environment as a system. A System Definition Matrix (SDM, page 67) may be useful here.

When identifying variables, there is a tendency to think only in terms of system components, e.g., organizational units. Thus skills used to identify system functions (Function Expansion, FEX, page 45) and system performance measures (Logical Framework, LGF, page 260) can be useful. Oval diagramming must be learned by repeated attempts at describing complex relationships.

TIME REQUIRED

Oval diagrams may be constructed either in a short time (less than an hour) or over a longer time (e.g., the life of a project), depending on the level of detail and internal consistency desired.

DESCRIPTION OF TOOL

SUPPLEMENTAL DEFINITIONS

1) A *causal chain* is a sequence of cause and effect relationships between variables (see figure 2).

2) A *causal loop* is a causal chain which is connected so that a change in any variable eventually feeds back through the chain to affect this variable. A causal loop has a *feedback* effect (see figure 2).

3) *Mutually-causal* variables occur when a change in one variable causes a change in another which is fed back to affect the first, e.g., a causal loop involving only two variables (see figure 2).

4) *Feedback structure* is the set of relationships describing a system that involves one or more interlocking causal loops (see figure 1).

5) *Correlation* is an observed relationship between two or more variables in which the changes in one variable may be associated with predictable changes in another; the relationship, however, is not necessarily cause-effect.

6) *Logical inconsistencies* occur when hypothesized relationships among variables are inconsistent. This may result from an imprecise variable definition, faulty logic, or a confusion of correlative behavior with cause-effect relationships.

Kinds of interactions:

1) A *direct effect* is an interaction between two variables so that a change in one results in a similar change in the other, i.e., either both increase or both decrease (see figure 3).

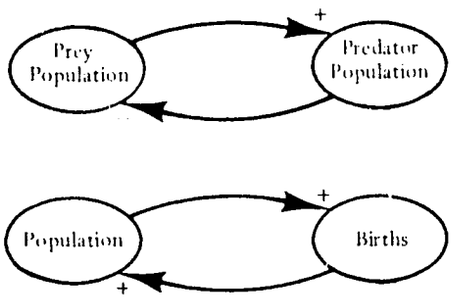
2) An *inverted effect* is an interaction between two variables so that a change in one results in an opposite change in the other, i.e., if one increases the other decreases, if one decreases the other increases (see figure 3).

3) A *threshold effect* occurs when one variable does not change until the other variable changes significantly (see figure 4).

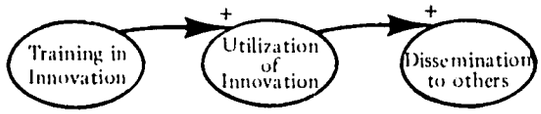
4) A variable interaction is *irreversible* if the variable only increases or only decreases (see figure 5).

FIGURE 2
Multiple Causal Relationships

Mutually Causal Variables



A Causal Chain



A Causal Loop: Feedback Effect

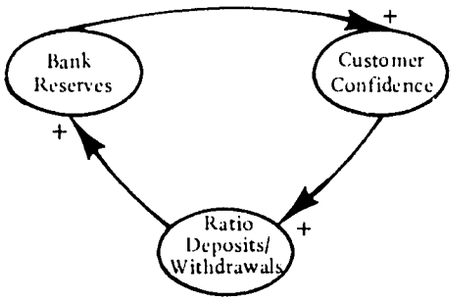


FIGURE 3
Types of Interaction Between Two Variables, A and B

	If A:	Then B:
Direct Effect	Increases	Increases
	Decreases	Decreases

EXAMPLES:

HYBRID SEED YIELDS (Variable A) influence NUMBER OF NEW ADOPTERS (Variable B)

POPULATION OF FERTILE FEMALES (Variable A) produces NUMBER OF BIRTHS (Variable B)

FERTILIZER APPLIED (Variable A) causes CROP YIELD (Variable B)

	If A:	Then B:
Inverted Effect	Increases	Decreases
	Decreases	Increases

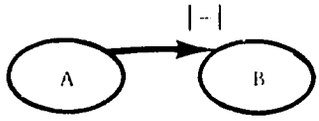
EXAMPLES:

ANTI-SMOKING ADVERTISING (Variable A) influences CIGARETTE CONSUMPTION (Variable B)

EXTENT OF FLOODING (Variable A) produces CROP YIELDS (Variable B)

CONTRACEPTIVES AVAILABLE (Variable A) causes NUMBER OF BIRTHS (Variable B)

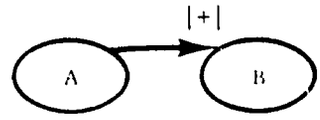
FIGURE 4
Illustration of Threshold Relationships



Inverted Threshold Effect	A must increase significantly before B decreases or A must decrease significantly before B increases

EXAMPLE:

When POLITICAL AGITATION (A) exceeds a level of tolerance, the LEVEL OF CIVIL LIBERTIES (B) is affected.

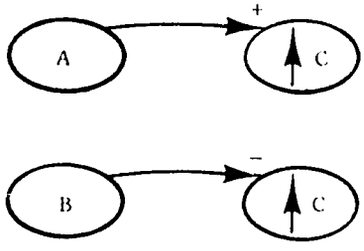


Direct Threshold Effect	A must increase significantly before B increases or A must decrease significantly before B decreases

EXAMPLE:

When COOPERATIVE MEMBERSHIP (A) exceeds a threshold number, FARMGATE PRICES (B) may be affected.

FIGURE 5
Illustration of Irreversible Effects

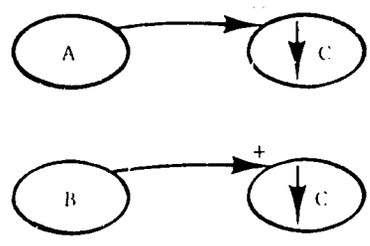


	If:	Then:
Irreversibly Increasing Variable	A increases, or B decreases	C increases
	Otherwise	C is unchanged

EXAMPLES:

Increasing PRICES (A) cause increasing WAGE DEMANDS (C)

Decreasing PASTURE RECOVERY RATE (B) causes increasing DESERTIFICATION (C)



	If:	Then:
Irreversibly Decreasing Variable	A decreases, or B increases	C decreases
	Otherwise	C is unchanged

EXAMPLES:

Increasing OIL CONSUMPTION (A) decreases (depletes) the OIL RESERVES (C)

Decreasing PRODUCT QUALITY (B) decreases (destroys) COMPANY REPUTATION (C)

REQUIRED INPUTS

Oval diagramming is most effective when the purpose is to increase understanding of a complex problem. Familiarity with the problem situation is therefore desirable, though much of the input will come from a basic understanding of relationships, e.g., the mental models that are formed from experience and observation.

When oval diagrams are constructed by a team, the members should broadly represent those concerned with the problem. More than five people working on one diagram limits effectiveness.

Tree diagrams (TRD, page 74) may be used to help identify variables. An interaction matrix diagram (IMD, page 92) is also useful for identifying the significant interactions.

TOOL OUTPUT

The output is an oval diagram which provides a graphic statement of the variables and relationships necessary to describe the system. The boundary of the system and the scope of possible interventions are defined.

The oval diagram focuses attention on the need for further information-gathering and testing of hypothesized relationships. The oval diagram provides the basic input to other techniques such as Scenarios (SCN, page 164) to gain greater understanding of system dynamic behavior.

IMPORTANT ASSUMPTIONS

Decision makers use mental models as well as more formal models to understand behavior and select choices of action. Mental models may be very complex, yet they are seldom made explicit except by inference from the actions of the decision makers. Oval diagramming depends on the ability of analysts (and decision makers) to picture the hypothesized relationships and the assumed causes and effects.

The assumed interactions between variables is identified by considering small changes in the causal variable. Relationships often change character when large magnitude variations occur, but an examination of this behavior is outside the province of this technique.

The oval diagram represents a definition of the system that is distinct from the environment. Setting a boundary between the system and its environment assumes a hierarchical relationship between systems and the larger systems which contain them. Hence, any environmental variable is part of an expanding systems hierarchy (see Tree Diagrams, TRD, page 74).

METHOD OF USE

GENERAL PROCEDURE

Oval diagramming is essentially a trial and error process. Therefore it is important to start diagramming immediately. The recommended procedure is to start* with a simple tree diagram (TRD, page 74) and when many factors keep reoccurring in different branches of the tree, to switch to an oval diagram.

1. **Construct a tree diagram of the system.**
   - 1.1 Identify variables for an influence tree.
   - 1.2 Select a starting variable which describes the condition or symptom of the problem in neutral terms.
   - 1.3 Construct the tree branches after each variable by identifying the variables which influence (or produce or cause) this variable to change value.
2. **Convert the influence tree to oval diagram form.**
   - 2.1 Locate the starting variable in the center.
   - 2.2 Cluster the influencing variables around it.
   - 2.3 Indicate the branching relationships as arrows between ovals.
   - 2.4 Form *causal chains* of variables.
   - 2.5 Do not repeat variables on the diagram. Form causal loops back to previously shown variables.
3. **Identify the types of interactions between variables.**
   - 3.1 Isolate two variables and imagine the effect that a small increase in the causal variable will have on the affected variable, assuming that all other factors do not change.
   - 3.2 Indicate whether the relationship is a *direct* or *inverted effect* (see figure 3).
   - 3.3 Indicate if a *threshold effect* is hypothesized (see figure 4).
   - 3.4 Indicate if the variable interaction is *irreversible* (see figure 5).
4. **Identify variables outside the system.**
   - 4.1 Apply the influence tree stopping rule (TRD, page 74) to identify any factor which is outside the influence of other variables within the system.
   - 4.2 Enclose these variables in a box to distinguish them from system variables (optional).
5. **Review the diagram for consistency.**
   - 5.1 See if the variables reflect a similar level of detail/aggregation.

*Oval diagrams may be constructed from Interaction Matrices (see IMD, page 92), but this emphasizes identifying all variables first, then determining the relationships.

FIGURE 6
Summary of Symbols and Notation for Oval Diagramming

SYMBOL	MEANING
	VARIABLE
	EXOGENOUS VARIABLE
	VARIABLE WHICH ONLY INCREASES
	VARIABLE WHICH ONLY DECREASES
	DIRECTION OF CAUSALITY
+	DIRECT EFFECT
-	INVERTED EFFECT
±	NATURE OF INTERACTION CHANGES
?	NATURE OF INTERACTION UNCERTAIN
|+| |-|	THRESHOLD EFFECT
a a	BREAK IN ARROW (FOR DIAGRAM CLARITY)

5.2 Eliminate any redundant relationships.

5.3 Look for spurious *correlations*, e.g., two variables which are shown as causally related when the apparent cause and effect interaction is actually the effect of a third variable. The classic example is the correlation between FIRE TRUCKS and FIRE DAMAGE. The number of fire trucks responding to a fire does not cause the amount of damage; the size of the fire affects both variables (DeNeufville, 1969).

5.4 Test the causal chains of hypotheses by considering the radiating effect of a small change in a variable in the chain. Are the sequences of interactions consistent with the observed behavior in the system?

6. **Complete the diagram for display or analysis.**

6.1 If necessary, redraw the diagram to clarify relationships (see figure 6).

6.2 Isolate causal loops and key variables by highlighting or diagramming them separately.

EXAMPLE

The eco-system problem which was diagrammed as an influence tree (see Tree Diagrams, TRD, page 74) will be continued.

Construct a Tree Diagram of the System

The tree diagram represents factors which interact to cause the nomad population's problems in the drought-stricken Sahel. A starting variable for the diagram was selected by first stating the known condition or symptom which describes the problem: the region is overpopulated with both people and animals. The tree diagram could have been started with OVERPOPULATION OF NOMADS or OVERSIZED HERDS. However these variables are not neutral, e.g., overpopulation is only relative to available resources. Consequently, HERD SIZE was selected* because it may either increase or decrease in relation to other variables. This permits the problem to be represented as the interaction among system variables.

Repeated application of the branching rule, "Identify the variables which influence this variable," for each newly identified variable resulted in the completed diagram shown in figure 7 (see Tree Diagrams, TRD, page 74). In practice, only a partial tree is needed to start the oval diagram.

*NOMAD POPULATION would have been an equally acceptable starting variable for the tree diagram.

Convert the Influence Tree to an Oval Diagram

The starting variable was drawn in the center with the variables which influence it clustered around (see figure 8). The branches of the tree diagram became arrows between the variables which became ovals. Each branch became a causal chain, and when a variable was repeated in the tree diagram (e.g., HERD SIZE) a causal loop was formed (see figure 9, the *mutually causal-relationship* between HERD SIZE and WATER AVAILABLE).

FIGURE 7
Influence Tree Diagram Prepared to Start Oval Diagram of Nomad Pastoralism Eco-System

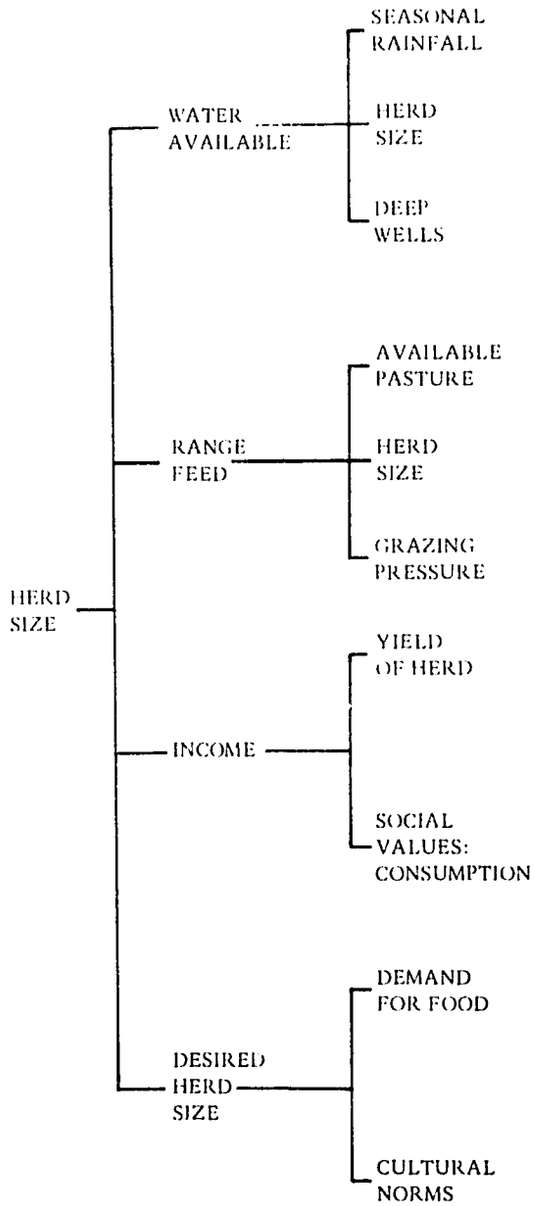
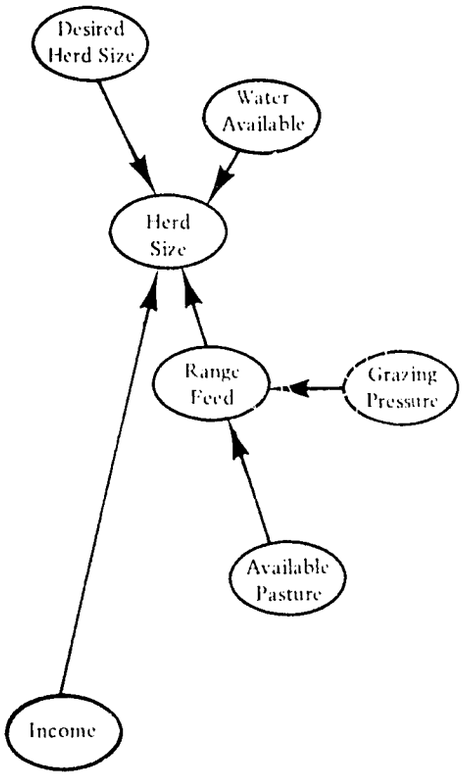


FIGURE 8
The Initial Steps in Constructing an Oval Diagram from a Tree Diagram



Identify the Types of Interactions Between Variables

If HERD SIZE were to increase by some small amount, the WATER AVAILABLE would decrease if all other factors were held constant. The – sign by the arrowhead on the relationship shown in figure 9 indicated this inverted relationship. By posing similar changes between each pair of related variables (considering only one relationship at a time), the analyst indicated on the diagram the hypothesized interaction between the variables.

One such hypothesis concerned the relationship between the RATE OF PASTURE RECOVERY and the AVAILABLE PASTURE. If the RATE increased slightly, the AVAILABLE PASTURE was directly affected. If the rate decreased below some threshold value, the relationship became distorted (DESERTIFICATION increased irreversibly, which decreased the AVAILABLE PASTURE). These hypotheses were noted on the oval diagram using the symbols shown in figure 9.

Identify Variables Outside the System

The SEASONAL RAINFALL was shown as a variable* which was outside the system. Although this variable produced the WATER AVAILABLE and influenced the RATE OF PASTURE RECOVERY, nothing within the system diagram was hypothesized to influence the SEASONAL RAINFALL.

Other factors were added to the oval diagram (see figure 1) to show the effects of external interventions on the system, e.g., digging DEEP WELLS or imposing RANGE LIMITATIONS and HERD CONTROL on the nomads by government interference. Each of these actions were determined by levels of variables within the system and could also be shown on the diagram** (e.g., the relationship between GRAZING PRESSURE and HERD SIZE CONTROL).

Review the Diagram for Consistency

One of the biggest problems in oval diagramming is to show widely varying levels of detail (disaggregated variables). In this example, all nomads and all livestock were aggregated into just two variables: POPULATION and HERD SIZE. The oval diagram could be restructured to show regional variables or tribal groups, but this detailing should follow a first attempt at a more general model.

A redundant relationship was shown initially in the oval diagram between HERD SIZE and RANGE FEED (compare figure 9 with figure 1). GRAZING PRESSURE was defined to link HERD SIZE with RATE OF PASTURE RECOVERY. When reviewing the diagram, it was observed that the effect of HERD SIZE on RANGE FEED was accounted for by the linkage through GRAZING PRESSURE.

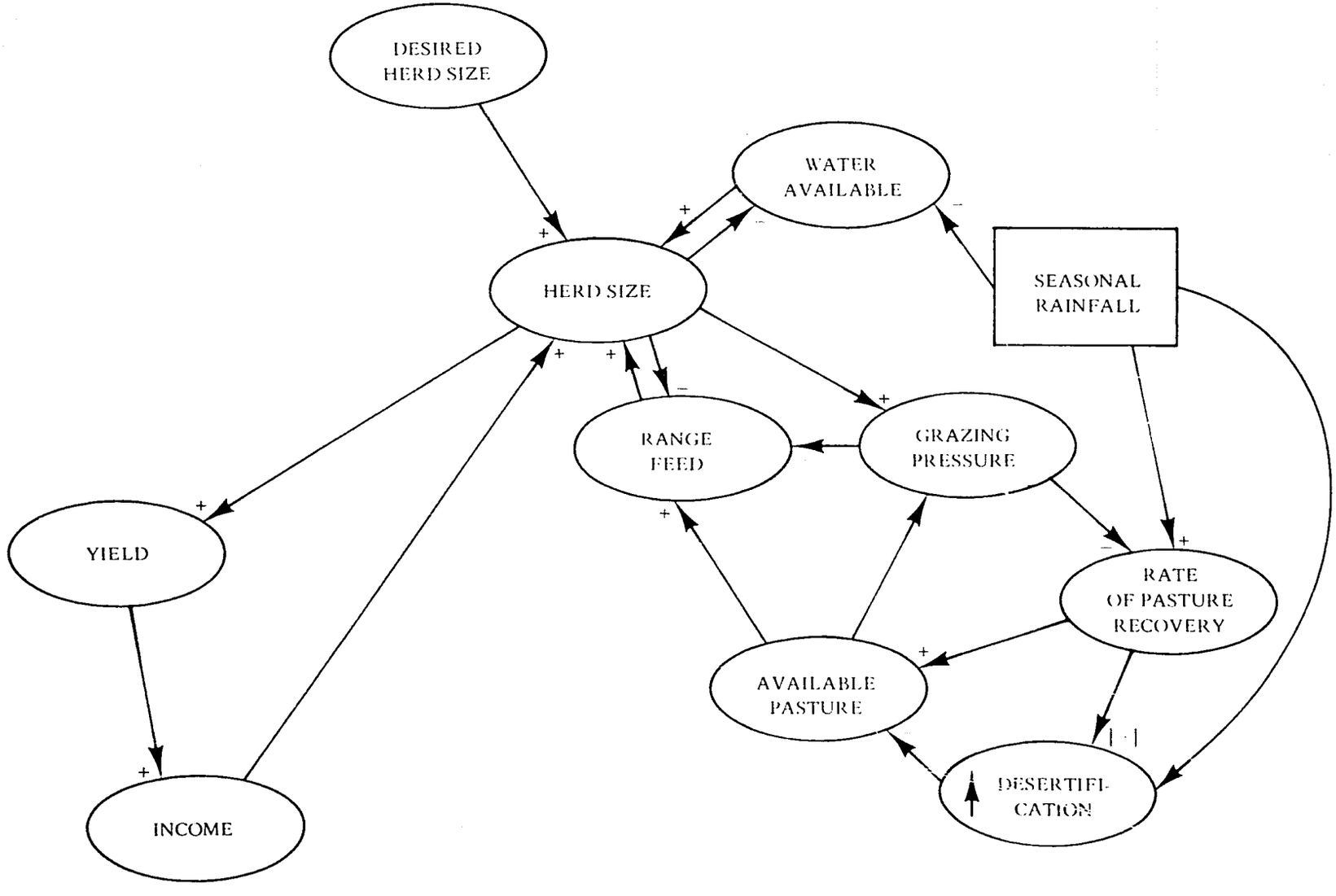
Social value relationships were shown rather ambiguously on the diagram. A relationship between DESIRED HERD SIZE and NOMAD POPULATION was hypothesized to include not only the DEMAND FOR FOOD but a set of CULTURAL NORMS. The norm may be a tradition that X cattle are desired for Y family members. Such a hypothesis requires that information be gathered for further study.

SOCIAL VALUES : CONSUMPTION influence how the YIELD from the HERD was to be taken – either to effect FOOD SUPPLY or to produce INCOME from milk or beef sales. The INCOME may be applied to further build up the HERD SIZE. By constructing these narratives, the hypothesized relationships represented in the oval diagram were systematically examined. It is important, however, to consider both increases and decreases in key variables.

*It would have been an error to depict DROUGHT as a variable since this is just a very low level of the neutral variable, SEASONAL RAINFALL.

**The relationships between outside interventions and system variables are described further in the continuation of this example in Interaction Matrix Diagrams (IMD, page 92).

FIGURE 9
Oval Diagram Depicting Causal Loops in Nomad Pastoralism Eco-System



Complete the Diagram for Display or Analysis

There were a number of interacting causal loops which led to the problems of the nomads. Each of these loops could be isolated for further analysis and perhaps programmed on a computer simulation model (CSM, page 120) (Picardi, 1974). For purposes of presentation to decision makers, it is desirable to isolate these major effects by redrawing the diagram or highlighting the relationships involved. Transparent overlays are effective in constructing the model before an audience. Color-coding and geometric shapes (other than ovals) are also effective in clarifying the complex causal hypotheses.

At the very least, this example illustrates the kinds of interactions which help to orient efficient information-gathering for detailed analysis and design.

THEORY

Oval diagramming, or causal modeling, draws from many disciplines including economics, sociology, business, and engineering. DeNeufville and Stafford (1969) describe the use of "arrow diagrams" to model the causal relationships between variables. The field of Systems Dynamics (Forrester, 1968) stems from efforts to model the complex relationships which lead to problematic behavior in industrial organizations. The MIT group subsequently attempted to model cities (Forrester, 1969) and the world (Meadows, 1972).

While these efforts were mainly concerned with developing a computer simulation model to test hypotheses and demonstrate the probable consequences of different policies, each must start with a causal model or oval diagram of the relationships to be tested.

The work of Harrison (1972) and Abraham (1975) is particularly noteworthy in their attempts to translate complex techniques into straightforward models of problematic system behavior.

A second approach concentrates on identifying the structure of interactions (see Interaction Matrix Diagrams, IMD, page 92). Interpretive Structural Modeling (Warfield, April, September, 1973; 1974) relies on computer assistance to manipulate the matrices of relationships into a model. An interaction matrix has a direct correspondence to an oval diagram and provides a powerful technique for automatically analyzing large numbers of complex interactions. Gerardin (1973) describes an application of the technique to planning, and at a recent conference (IEEE Conference, 1976) several authors applied the technique to development problems.

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Interaction Matrix Diagramming

PREREQUISITE TOOLS

Tree Diagrams (TRD, page 74) and Oval Diagramming (OVD, page 81).

USAGE

PURPOSE

Interaction matrix diagrams describe complex relationships by identifying self-interactions within members of a set and cross-interactions between members of different sets of elements.

USES

Interaction matrices may be used singly or in combination to:

1) Identify the elements (e.g., objectives, constraints, or system variables relevant to the description of a problem, project, or system).

2) Systematically explore the possible interactions within a set of elements, using a *self-interaction matrix*.

3) Indicate the existence, strength, importance, or direction of an interaction between any two elements.

4) Identify the interactions between two different sets of factors, e.g., between project objectives and activities.

5) Provide a matrix checklist for record keeping, communication, and planning.

KEY DEFINITIONS

1) A *matrix* is a mathematical and graphical representation in two dimensions.

2) A *self-interaction matrix* represents relationships within a single set of variables.

3) A *cross-interaction matrix* represents relationships between dissimilar sets of variables.

4) A *reduced matrix* is formed by omitting one or more rows or columns from the original matrix.

5) A *set* is a collection of elements having some common property.

6) A *matrix entry* is the symbol used to indicate the existence or absence of a relationship between the element in the row and the element in the column (which together define the entry).

SHORT DESCRIPTION

Interaction matrices provide a technique for first identifying the members of a *set* of elements, e.g., the objectives for a project, and then systematically examining all the possible interactions among members of the set. If the factors can be categorized, the cross-interactions between members of different categories can be determined (see figure 1). A *matrix entry* may show a range of information, including whether the relationship between the two *elements* has been hypothetically or empirically determined, or whether the relationship is or would be desirable if it were established. The matrix entry may also show the

relative strength or importance of the interaction. Interaction matrices correspond directly to tree diagrams (TRD, page 74) and oval diagrams (OVD, page 81).

ADVANTAGES

1) All factors relevant to the description of a problem or system are identified in a separate exercise prior to specifying interactions.

2) All possible interactions between elements are examined in a systematic procedure which minimizes omissions and tests for inconsistencies.

3) The existence of a relationship is determined without having to further specify the type or degree of interaction.

4) A large number of variables may be analyzed without significantly affecting the clarity or utility.

5) The matrix provides a convenient means of recording information and tasks for further study.

6) The procedure lends itself to a multi-disciplinary approach.

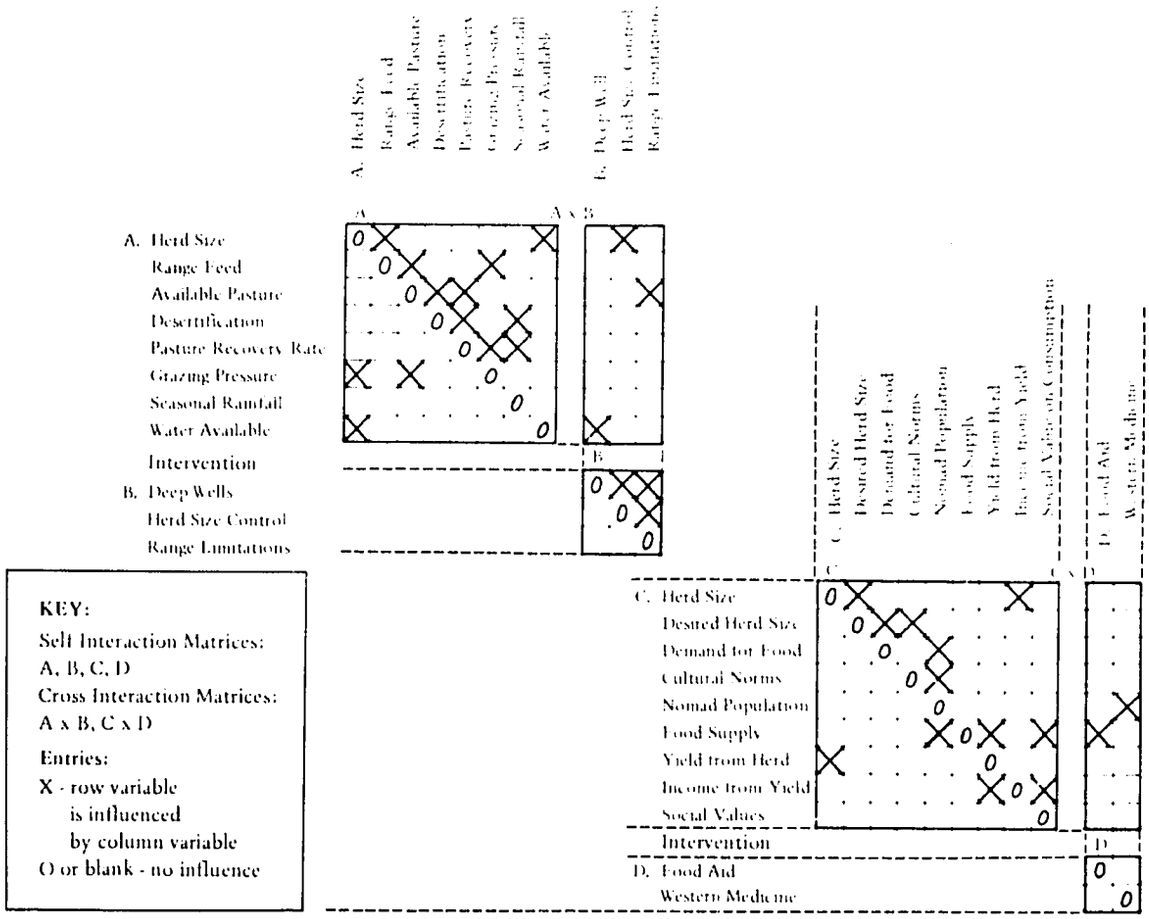
LIMITATIONS

1) Separating the tasks of generating elements and identifying relationships may run counter to thought processes, e.g., tracing cause-effect chains or the order of preference among descriptive elements. In these processes, new elements often emerge as relationships are examined (see Tree Diagrams, TRD, page 74).

2) The number of relationships to be examined increases as the square of the number of matrix elements, e.g., there are nine possible interaction pairs among three elements.* Fortunately, not all interactions need to be examined, but the process can be time-consuming.

*This assumes that the interaction of an element with itself must be examined.

FIGURE 1
Interaction Matrix Diagram Derived from Oval Diagram of Nomad Pastoralism Relationships



3) Tracing cyclical relationships and other linkages through the matrix structure can be confusing. An oval or tree diagram provides greater clarity than the matrix format.

REQUIRED RESOURCES

LEVEL OF EFFORT

Construction of interaction matrix diagrams requires two distinct tasks: identifying relevant elements, and analyzing interactions among them. The first task may exploit the collective judgment of a large group using brainstorming (BSG, page 3) or the Nominal Group Technique (NGT, page 14). Secondary information sources may also be used to develop the list.

The task of identifying relationships requires considerable effort and expertise. This may be a team task if care is taken to explain the elements and the relationship which is to be examined.

SKILL LEVEL

Some skill is required to diagram the interaction matrices in order to preserve clarity, and to interpret the linkages between elements.

TIME REQUIRED

The construction of an interaction matrix for a relatively small number of factors may take hours, depending on one's ability to assess the matrix entries and the amount of information included.

SPECIAL REQUIREMENTS

Interaction matrix diagrams may be constructed using special computer programs. This greatly facilitates the systematic analysis of many elements and permits quick and accurate performance of matrix operations (Warfield, 1974).

DESCRIPTION OF TOOL

SUPPLEMENTAL DEFINITIONS

1) A *transitive relationship* requires that a directed relationship among three or more elements be consistent, e.g., if A is preferred to B, and if B is preferred to C, then A must be preferred to C (see figure 2).

2) A *directed relationship* specifies that the existence of the relationship is dependent on the order in which the two elements are considered, e.g., "is influenced by," "is preferred to," and "is subordinate to."

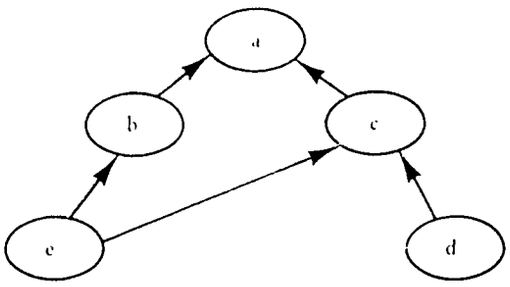
FIGURE 2
Properties of Relationships

Self-Interaction Matrix of Relationship R

	a	b	c	d	e
a	0	0	0	0	0
b	1	0	0	0	0
c	1	0	0	0	0
d	0	0	1	0	0
e	0	1	1	0	0

NOTE: "1" means that row element *i* is related to column element *j*. "0" means that relationship *R* does not apply between the elements.

Oval Diagram of Matrix Assuming a Directed, Intransitive, Asymmetrical and Irreflexive Relationship *R*



SYMBOL DEFINITIONS:

a, b, c, d, and e are elements of a set.
i, j are any two elements.
R denotes a relationship between any two elements, a R b signifies that element *a* is related to element *b* by the relationship R.

MATRIX RELATIONSHIP PROPERTIES

Reflexivity. A relationship is reflexive if a R a, b R b, . . ., i R i. If not, the relationship is *irreflexive* because all the diagonal elements are "0."

Symmetry. A relationship between two elements is symmetrical if when i R j, then j R i. For example, Group A "communicates with (R)" Group B. In this case, the two halves of the matrix are symmetrical about the diagonal. If not, then the relationship is *assymetrical.*

Transitivity. A relationship is transitive if when a R b and b R d then a R d. For example, project A "is preferred to (R)" project B which is preferred to Project D, therefore Project A must be preferred to Project D. If not, the relationship is *intransitive.* The entries at column *a* of rows *b* and *e* are different, indicating an intransitive relationship (or an inconsistent matrix entry).

3) A *reflexive relationship* occurs when the variable interacts with itself (see figure 2).

4) A *symmetrical relationship* means that the relationship between two elements is non-directed, i.e., the elements interact independent of the order in which they are considered (see figure 2).

5) *Linearly linked matrices* have a common set of rows or columns.

6) *Orthogonally linked matrices* have the same set of elements in the rows of one matrix and the columns of the other matrix.

REQUIRED INPUTS

If the interaction matrix diagram is to be a group effort, team members should be familiar with the problem or project. They should have diverse backgrounds in order to provide a broad perspective on relevant elements and possible relationships.

TOOL OUTPUT

The interaction matrix diagram provides a useful model, but may also be an intermediate product which is used to guide further information-gathering and study.

IMPORTANT ASSUMPTIONS

The diagramming process represents a mapping of an internal mental model to an explicit format (matrices). The technique systematizes the mapping process by examining only one pair of elements at a time. This may result in a relationship between two elements which is inconsistent with the interaction of each element to other elements (e.g., a *transitive relationship* among elements is violated). In this case, it must be assumed that the mental model is incorrect, though a cognitively complex view of the relationship may be the source of the discrepancy.

METHOD OF USE

GENERAL PROCEDURE

Throughout the following procedure, remember that interaction matrices are constructed by simply making an entry at the intersection of a row and column which indicates whether there is a specified relationship between the corresponding elements.

1. **Specify the type of elements and the relationship.**
   - 1.1 Specify if the element set is objectives, constraints, agencies, needs, variables, interventions, etc.
   - 1.2 Specify if the relationship is directed or non-directed, e.g., non-directed relationships include "is associated with," "communicates with," and "interacts with."
   - 1.3 If the relationship is directed, i.e., from one element to the other, then specify if the relationship is transitive or intransitive (see definitions in figure 2).
   - 1.4 Specify if the relationship is *reflexive* or not (see figure 2).

2. **Generate a list of elements for each set.**
   - 2.1 Ask the question: What elements are necessary to describe the "type of element" for the "context"? For example, "What elements are necessary to describe the objectives of an integrated rural development project?"
   - 2.2 Combine individual answers to this question if a group process is used, e.g., brainstorming (BSG, page 3), Nominal Group Technique (NGT, page 14), or Delphi (DLP, page 168).

3. **Construct the interaction matrices.**
   - 3.1 List all the elements of one type in the rows of a matrix.
   - 3.2 Prepare a self-interaction matrix by repeating this list of elements as the columns of the matrix to form a square (see figure 1).
   - 3.3 Prepare a cross-interaction matrix by listing elements from a different set in the columns of the matrix to form a rectangular matrix (see figure 1).

4. **Determine matrix entries.**
   - 4.1 Specify the symbol for a positive entry to indicate the existence of a relationship, e.g., "/," "X," or "1" (see also figure 1).
   - 4.2 Specify the symbol which indicates that there is no interaction between two variables (e.g., "0" or blank).
   - 4.3 Beginning with the first row of the matrix, apply the relationship test to the row element and each column element. Test by asking: Is (element *i*) (relationship) (element *j*)? For example, "Is Project A *preferred* to Project B?" or "Is variable X *influenced* by variable Y?"
   - 4.4 If the answer to the relationship test is positive, then the corresponding matrix entry is the positive symbol specified in step 4.1. If not, either enter "0" or make no entry.
   - 4.5 If a group process is used to examine each relationship, use a majority vote or group consensus to answer the relationship test.

4.6 Repeat this test for the entries in the remaining matrix rows until all possible matrix entries have been determined.

5. Examine the matrix for consistency.
   - 5.1 If the relationship is reflexive, confirm that the diagonal entries are positive (see example, figure 2).
   - 5.2 If the relationship is irreflexive, the diagonal entries should be zero.
   - 5.3 If the relationship is symmetrical (e.g., a non-directed relationship such as "is associated with"), then confirm that each positive row *i*-column *j* entry in a self interaction matrix has a corresponding row *j* column *i* entry which is positive. Otherwise, the matrix entry is inconsistent (see example, figure 2).
   - 5.4 If the relationship is directed and transitive, follow the iterative procedure shown in figure 3 to test whether an intransitive relationship has been erroneously entered in the matrix. For example, assume that the matrix in figure 2 describes a relationship between elements which is transitive, e.g., element *i* is subordinate to element *j*. Comparing the positive entries in the bottom row (*e*) with the positive entries in row *b* (step 7 in the test sequence) indicates that the column *a* entries are inconsistent. If *e* is subordinate to *b*, and if *b* is subordinate to *a*, then *e* must be subordinate to *a* or the relationships would be intransitive.

6. Specify the relative degree that the relationship applies (optional).
   - 6.1 Determine a scale to indicate the degree of interaction (e.g., 0 to 10, or 0 to 3) (see Rating Scales, RTS, page 29).
   - 6.2 For each row, assign a scale value to the entries which indicates a relationship. The value determined should reflect the relative degree to which the relationship applies compared to the other relationships in that row, e.g., the strength of interaction between the two variable elements (see example on page 99).

7. Construct a reduced matrix (optional).
   - 7.1 Eliminate any elements from a cross-interaction matrix which have no positive relationships with elements in the other set by striking the row or column from the matrix.
   - 7.2 Eliminate any element in a self-interaction matrix only if it has no positive row *and* column entries, e.g., it does not interact with any other element within the set.
   - 7.3 Eliminate any element where the degree of relationship is shown as an entry if none of the entries for that element are above a specified scale value (see example on page 99).

8. Construct an interaction matrix diagram (optional).
   - 8.1 Two interaction matrices may be linked together by repeating one or more elements of one set in both matrices (see HERD SIZE in matrices A and C in figure 1).
   - 8.2 Matrices may be linked together by alternating cross- and self-interaction matrices (see figure 1) to form *linearly linked matrices* or *orthogonally linked matrices*. For the latter, the self-interaction matrix becomes a pivot point between two cross-interaction matrices.

9. Clarify the interaction matrix by constructing a tree diagram (optional).
   - 9.1 Select a row of the matrix as the starting element of the tree (see Tree Diagrams, TRD, page 74).
   - 9.2 Branch the tree at each positive column entry. The element on the branch corresponds to the column element.
   - 9.3 For each of these elements the process may be repeated by branching at the positive entries on their respective rows. For the matrix in figure 2, a tree started with the element *e* would first branch to elements *b* and *c*, each of which would branch to element *a*. The branching rule in this procedure is simply the interaction matrix relationship, e.g., identify all the elements to which this element is subordinate.
   - 9.4 To tree diagram the converse of the relationship, repeat the above procedure, but branch in each case at the positive entries in the *column* of the element. The branching rule then becomes in effect flipped around, e.g., identify all the elements which are subordinate to this element. The oval diagram in figure 2 resembles such a tree structure, except that element *e* is not shown twice.

10. Clarify the interaction matrix by constructing an oval diagram (optional).
    - 10.1 Select the row element with the most positive entries as the starting element.
    - 10.2 Cluster all the elements which have positive column entries about the starting element.
    - 10.3 Draw lines which correspond to the relationship between each of the elements of a positive matrix entry.

FIGURE 3
Examining an Interaction Matrix for Intransitive Relationships

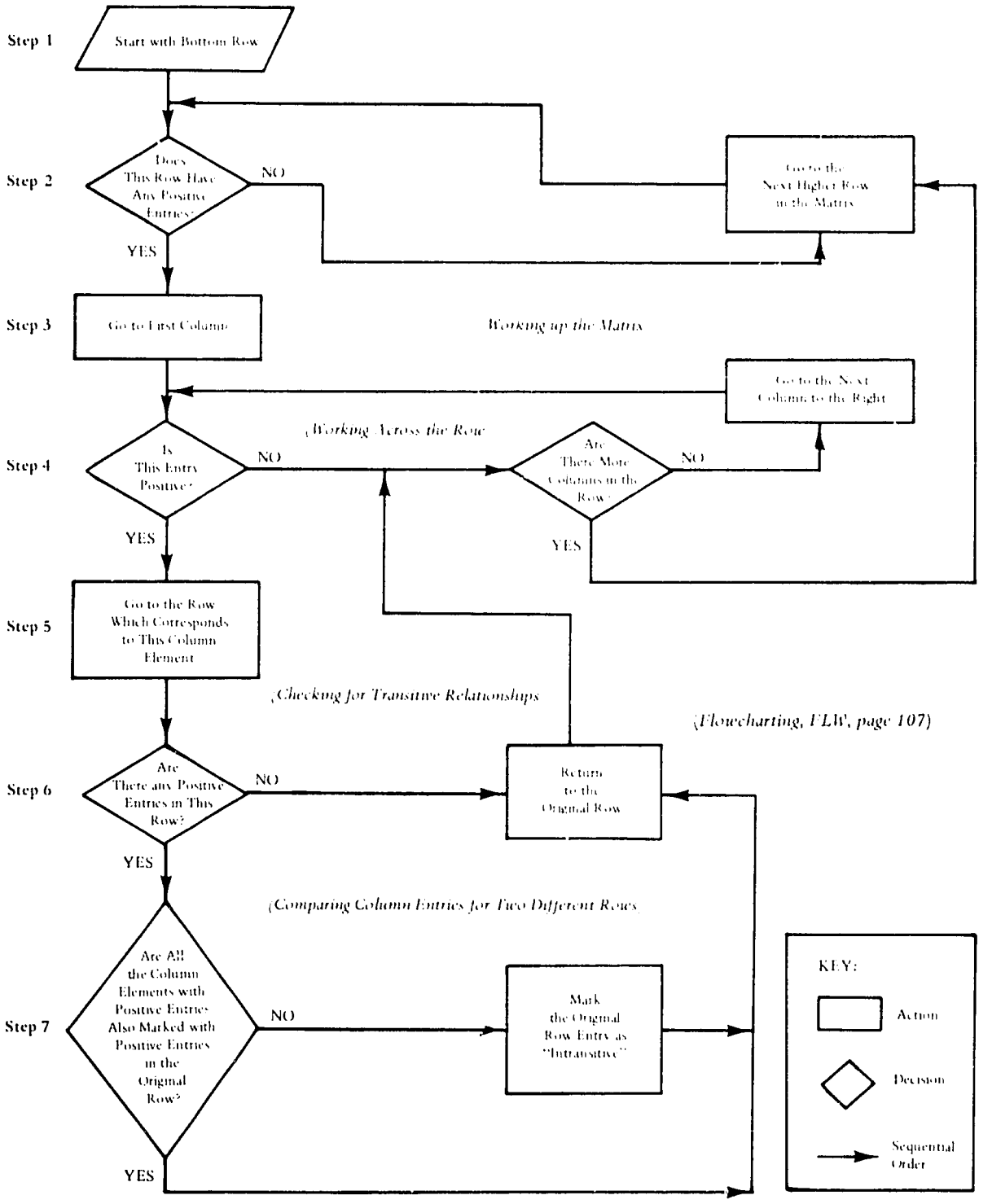


FIGURE 4
Reduced Cross-Interaction Matrix for Environmental Assessment

Existing environmental characteristics or conditions \ Actions which can impact environment	A.e Alteration of ground cover	A.f Alteration of drainage	B.b Industrial sites and buildings	B.r Cuts and fills	D.e Energy generation	H.h Cooling water discharge
A.2d Water quality				4/4		
A.2e Water temperature						5/2
A.4b Erosion		5/3		4/2		
A.4c Deposition				4/1		
B.1a Trees				4/2		
C.1a Wilderness and open spaces	3/2		4/4	4/4		
C.3b Wilderness qualities	3/2		4/4	4/4		
C.ef Parks and reserves	6/4		6/4			
C.3h Rare and unique ecosystem			4/10			
C.5b Transportation network					6/3	
C.5c Utility network					2/4	

KEY:

6/4 — Relative magnitude of the interaction on a scale of 1 to 10
Relative significance of the interaction on a scale of 1 to 10

SOURCE: Agency for International Development. *Environmental Assessment Guidelines Manual.* Washington, D.C.: USAID, September 1974.

10.4 If the relationship is directed, e.g., "*a* is preferred to *b*," locate the arrowhead at the end of the linkage in a way consistent with the meaning of the relationship. For example, the oval diagram for the matrix in figure 2 places the arrowhead at the oval surrounding the element which is second in the relationship "*b* is subordinate to *a*."

10.5 Add remaining elements and links to the diagram where each link corresponds to a positive entry on the matrix.

10.6 If the relationship is symmetrical, only the positive entries on one side of the matrix diagonal need to be diagrammed.

10.7 If the relationship is reflexive, an arrow may be shown emitting from the oval and looping back to it, though such links are often omitted.

10.8 If the relationship is transitive, the matrix will contain a number of entries which represent redundant links on an oval diagram. These may be omitted as shown in the link arrows from *e* to *a* and *d* to *a* in figure 2.

10.9 An intransitive relationship may be oval diagrammed as a feedback loop, e.g., the relationship "is affected by."

10.10 Confirm that the diagram is complete by counting the number of connecting arrows, any omitted reflexive loops, and any omitted redundant intransitive links. The total should equal the number of positive matrix entries.

10.11 The information on degree of relationship may be transferred to the oval diagram by associating the scale number with the connecting arrow (e.g., either adjacent to the arrowhead or on a box on the arrow).

EXAMPLES

Constructing a Reduced Cross-Interaction Matrix

A set of existing environmental characteristics or conditions, such as water quality and erosion, were identified and listed by various categories to reflect the environmental concerns of donor-funded development projects (*Environmental Assessment Guidelines Manual*, 1974). A second set of actions which can influence the environment were also identified by using several categories of actions. These included "alteration of ground cover," energy generation," etc.

A sample environmental assessment was then conducted by constructing a cross-interaction matrix which listed the environmental characteristics as rows and the actions as columns (see figure 4). Matrix entries were scaled from 1 to 10 (see Rating Scales, RTS, page 29). The first entry for each combination of condition was determined by an assessment of the relative strength of the interaction. This was done for every probable combination. A second entry assessed the relative significance of the interaction. Finally, a reduced cross-interaction matrix was formed by eliminating the rows and columns. The reduced matrix contained only those elements whose interaction had a strength or significance greater than 2 on the relative scale.

This matrix pinpointed the probable areas where project actions may have either a strong or significant environmental impact.

An Interaction Matrix Diagram of the Nomad Pastoralism Eco-System

The problems of the nomads in the drought stricken Sahel were represented as a tree diagram (TRD, page 74) and an oval diagram (OVD, page 81). The oval diagram showed the relationships among a set of variables which described the nomad pastoralist eco-system, and key economic and social variables such as the SOCIAL VALUE ON CONSUMPTION (see figure 5). Self-interaction matrices were constructed for the two parts of this diagram: the livestock-environmental and the population-socioeconomic variables (see figure 1, matrices A and C). In each case, the outside interventions (shown as boxed variables in figure 5) were diagrammed as separate matrices (B and D).

The interaction matrix diagram provides a systematic way of examining the multiple interactions between an outside intervention and the internal system variables.

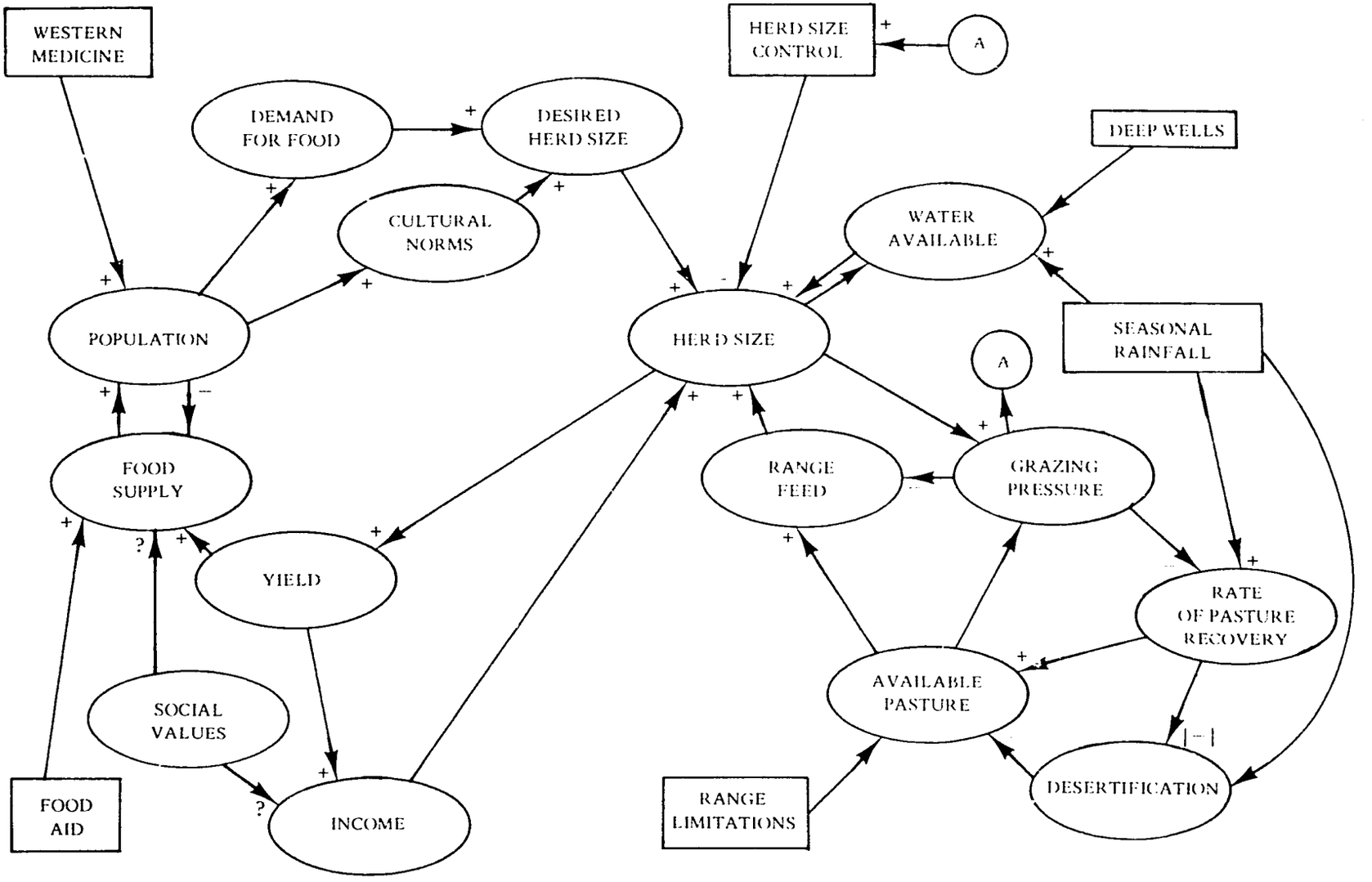
The cross-interaction matrices AXB and CXD were constructed to determine which system variables were influenced by the outside interventions (see figure 1). As the oval diagram indicates (figure 5), these interventions were originally diagrammed as affecting only a single system variable.

The cross-interaction matrix AXB was further specified by starting with the column DEEP WELLS and asking, for each row variable: Does this intervention (digging deep wells) influence this variable? Additional positive entries are shown in figure 6 as slashes in the cross-interaction matrix.

In order to determine the possible influence of system variables on the intervention (i.e., *mutual-causal relationships*—see OVD, page 81) the BXA and DXC cross-interaction matrices* were constructed, and the entries for each row element (intervention) were determined by

*Note that AXB and BXA are orthogonally linked matrices while BXA and BXC are linearly linked matrices.

FIGURE 5
Oval Diagram for Nomad Pastoralism Eco-System



the relationship test: Does this column variable influence this row intervention in the system? Positive responses are shown as slashes entered on the diagram (see figure 6).

Subjecting the diagram to this systematic process revealed some omissions in the original conception of the complex eco-system relationships. For example, HERD SIZE CONTROL affected a number of other variables besides the HERD SIZE. One in particular which should not have been slighted is the necessity to influence the DESIRED HERD SIZE variable of the nomad pastoralist decision maker. Also, the crucial interaction between HERD SIZE CONTROL and RANGE LIMITATIONS is pinpointed. Other interventions such as VETERINARY SERVICES can be added to examine further interactions.

The oval diagram may then have been redrawn to form the interaction matrix diagram to show these additional hypothesized relationships.

Constructing a Tree Diagram to Clarify Relationships

Multiple relationships may be lost in the complexity of the matrix format. A simple way to clarify the diagram is to construct a tree diagram (TRD, page 74) of the interactions. A tree diagram is shown for the relationships of HERD SIZE CONTROL to other elements of the description (see figure 7). The right-hand tree lists the factors which influence the intervention of HERD SIZE CONTROL. The right-hand branches represent the positive entries in the column labeled HERD SIZE CONTROL. The left side describes variables which are influenced by this intervention. The left-hand branches are the entries in the row with the same label.

Some items are duplicated on both lists, indicating that attempting to control HERD SIZE is a complex process involving feedback of variables such as HERD SIZE and GRAZING PRESSURE on range lands.

FIGURE 6
Revised Interaction Matrix Diagram Showing Influences on Interventions in System

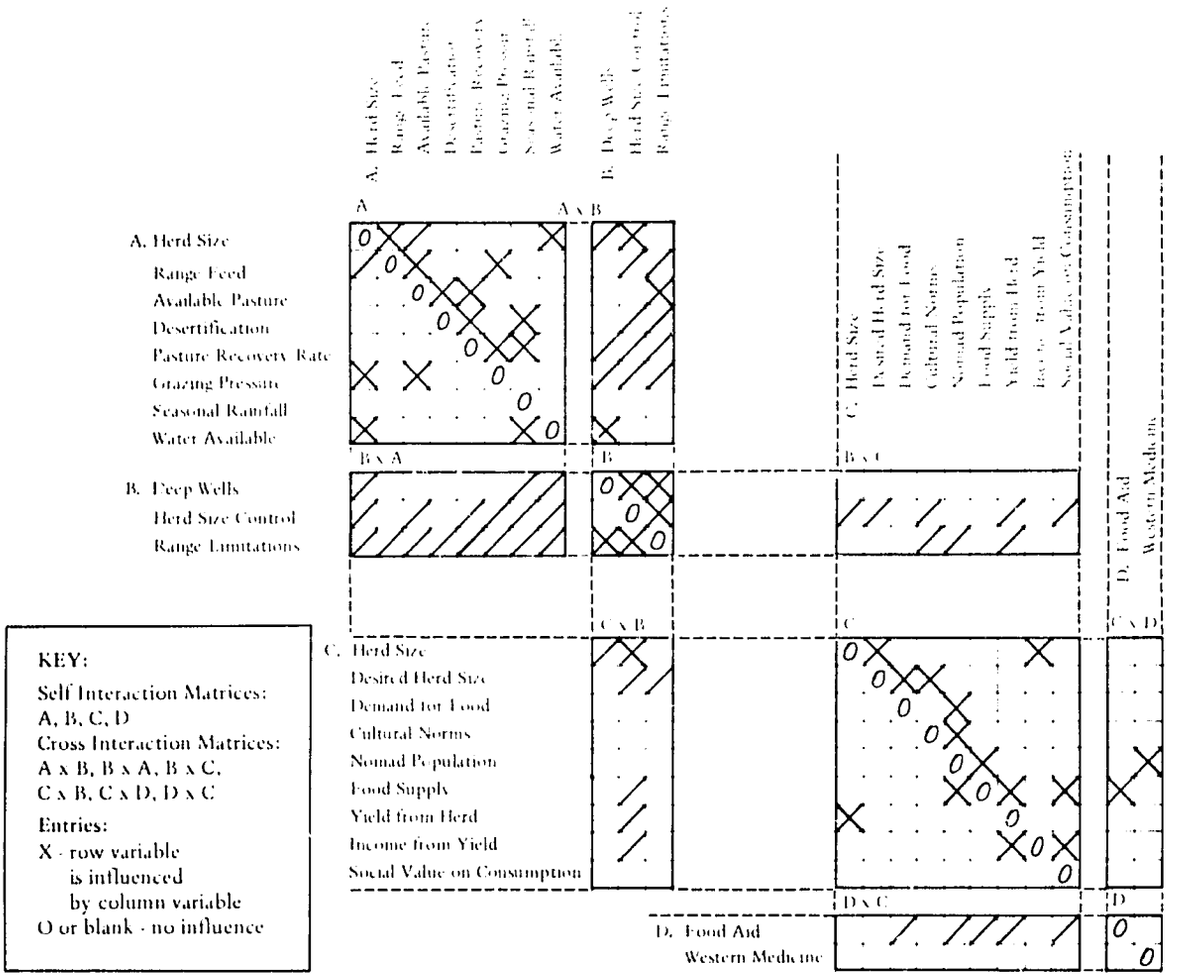
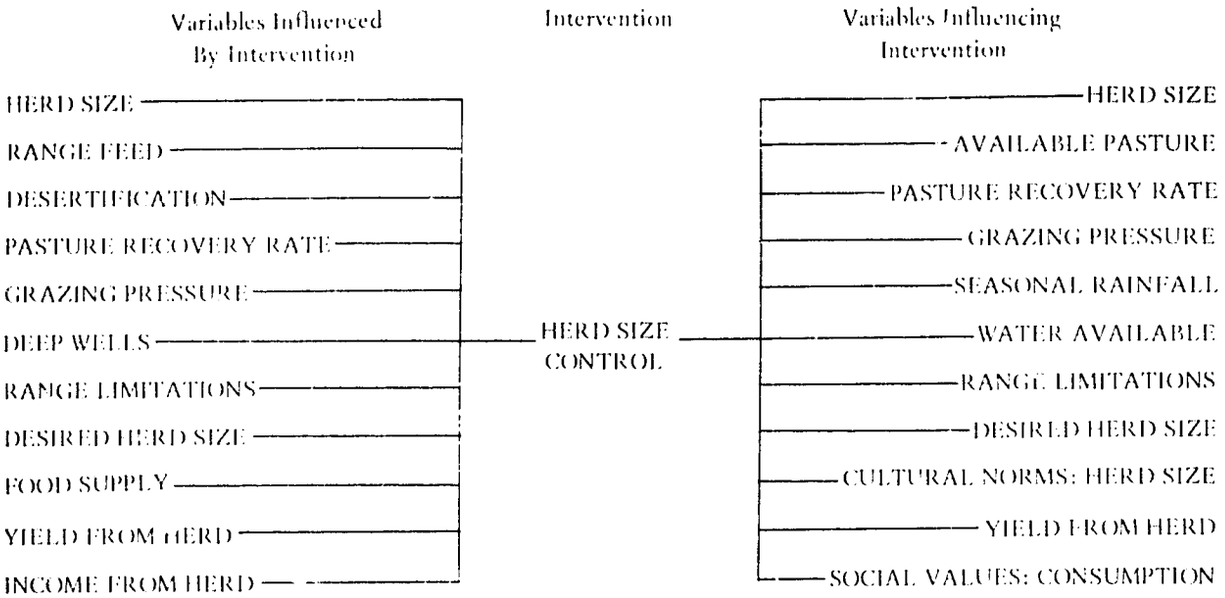


FIGURE 7
Tree Diagram Clarifying the Influence
Relationships in the Interaction Matrix Diagram Example



The problems of the nomad pastoralists in the Sahel have been addressed using Interpretive Structural Models in two recent papers (Geiger and Fitz, 1976, and Hornbach, et al., 1976). The papers present oval and tree diagrams which were derived with the assistance of special computer programs designed to transfer the interaction matrix representations.

THEORY

The matrix representation of relationships takes many forms, and the relevant theory depends on the particular application. Beckett (1971) traces the representation of systems from directed graphs (oval diagrams) to matrix models (interaction matrices) to Markov transition models. The latter builds on probability theory with the matrix entries representing the probability of a transition from one system state to another.

Interaction matrix diagramming owes a great deal to the efforts of Warfield and others at the Battelle Memorial Institute (Hill and Warfield, 1972). Their "Unified Program Planning" uses the self-interaction and cross-interaction matrix approach to structure the following sets of planning elements:

Constraints
Needs
Objectives (and measures)
Alterables
Agencies (and agents)
Activities (and measures)
Societal sectors

These techniques and others are described in *Portraits of Complexity* (1975).

Interpretive Structural Modeling is the label for a range of computer-assisted diagramming techniques which grew out of the work at Battelle (Warfield, April, September, 1973; 1974). It relies on computer assistance to manipulate the matrices of relationships into a model and provides a powerful technique for automatically analyzing large numbers of complex interactions. The basis for computer assistance is found in the properties of directed graphs and matrix partitioning. These techniques may be performed manually, but are tedious for large matrices.

Gerardin (1973) describes an application of the technique to planning, and at a recent conference (IEEE Conference, 1976) several authors applied the technique to development problems.

The interaction matrix diagramming technique extracts the most useful elements of Interpretive Structural Modeling and the more heuristically oriented Unified Program Planning.

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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, DLP, HIS, IVW, SVY
Rating Scales
CBA, CGA, DLP, DTR, MCU, NGT, SPA
Regression Forecasting
OVD, SVY
Scenarios
DLP, GAM, OVD
Subjective Probability Assessment
DLP, DTR, IVW, RTS
Surveys
CBA, CEA, DLP, GNT, HIS, IVW, QTN, RGF, RTS
Synectics
NGT, RTS
System Definition Matrix
BSG, CBA, CSM, FEX, GAM, IDL, LGF, NGT, SCN
Tree Diagrams
DTR, IMD, OBT, OVD

Glossary

ACTION STUB. That portion of a decision table which lists the actions or decisions to be taken if a particular combination of circumstances occurs (DTB).

ACTION-EVENT PATH. The sequence of alternative actions and relevant events represented by the branches in a decision tree (DTR).

ACTIVITY. An operation with a well-defined beginning and end and a specific purpose (CPM).

AND LOGIC ELEMENT. Links sub-objectives to objectives where all sub-objectives must be achieved in order to attain the higher level objective(s) (INS).

ANNUAL CASH FLOW. The net incremental benefits for each year of a project and the difference between the incremental benefits and costs (CFA).

ASSESSOR. A person who estimates the probability distribution of a set of events (SPA).

ATTRIBUTE. The elements or components of the system and the interrelationships among them (MPA, SCN).

AXIOLOGICAL MEASUREMENT. Involves value judgments. where the data necessary to determine accomplishment of an objective are gathered via subjective methods (OBT).

BASE SYSTEM STATE. The set of current conditions which describes the essential characteristics of the scenario (SCN).

BINARY-EVENT OBJECTIVE. An objective that either clearly occurs or does not occur (OBT).

BRANCHING RULE. A rule that governs the construction of relationships in a tree diagram (TRD).

CAUSAL CHAIN. A sequence of cause and effect relationships between variables (OVD).

CAUSAL LOOP. A causal chain which is connected so that a change in any variable eventually feeds back through the chain to affect this variable (OVD).

CENSUS. A survey of all members of a subject population (SVY).

CENTRAL TENDENCY. The most likely, or average value of the variable (HIS).

CHECKLIST. Used in design or analysis where items are marked or otherwise noted item by item (SDM).

CLASS INTERVAL. A uniform division of the variable range (HIS).

CLOSED QUESTIONS. Questions which require the respondent to limit responses to prespecified categories (QTN).

CLUSTER SAMPLE. The process of randomly selecting several clusters of subgroups from the total population and surveying all members of the selected subgroups (SVY).

CLUSTERED DATA. Used to aggregate the data into fewer points for analysis and plotting (HIS).

COMPONENTS. An entity in a system which may be elemental, or it may be a subsystem having distinct components (SDM, TRD).

CONDITION ENTRIES. The conditions of each factor (or question) listed in the condition stub (DTB).

CONDITION STUB. That portion of a decision table which lists the factors to be considered when making decisions in a given situation. Each factor is written in the form of a question (DTB).

CONTINGENCY. A particular combination of factors that describes a future environment (CGA).

CONTINUOUS MODEL. A model which treats variables that change continuously over time (CSM).

CONTINUOUS VARIABLE. Takes on an infinite number of values over some range of possible values (HIS).

CONTROL DIMENSION. Evaluates and regulates any element's specification. This dimension measures each element as the system operates, compares the measure to what is designed or desired, and takes action if the difference is greater than desired (SDM).

CORRELATION. An observed relationship between two or more variables in which the changes in one variable may be associated with predictable changes in another; the relationship, however, is not necessarily cause-effect (OVD).

CORRELATIVE BEHAVIOR. An assumed relationship between two or more variables in which the changes in one variable may be associated with predictable changes in the others (RGF).

CRITICAL ACTIVITY. An activity which, if not completed on time, will delay the entire project (CPM).

CRITICAL PATH. The sequence of critical activities from project start to project finish that determine the shortest project duration (CPM).

CROSS-INTERACTION MATRIX. A representation of relationships between dissimilar sets of variables (IMD).

DECISION RULES. The action entries of a decision table which link a particular combination of condition entries to specified actions (DTB).

DECISION SYMBOL. Represents a step in a process where there is a choice among two or more alternative actions (FLW).

DEPENDENT VARIABLE. The variable being forecast (RGF).

DESCRIPTIVE MODEL. A representation or imaginary entity containing information in a predefined form, intended to be interpreted by its user rules (SDM).

DETERMINISTIC MEASUREMENT. Where the realization of the objective is unequivocally determined from numerical data (OBT).

DIMENSION. Collections of attributes of the system, where each collection represents a major aspect of the system (SCN).

DIRECT ANALOGY. Compares the problem being faced to a parallel situation in another field, technology, or discipline (SCN).

DIRECT ANALOGY METHOD. Used in Synectics sessions when members compare the problem being faced to a parallel situation in another field, technology, or discipline (SYN).

DIRECT EFFECT. An interaction between two variables so that a change in one results in a similar change in the other (OVD).

DIRECT MARKET VALUES. Measures of project costs or benefits which are assessed from equivalent market prices (IPX).

DIRECTED LINE. Links two symbols together with an arrowhead indicating the sequence (FLW).

DIRECTED RELATIONSHIP. Specifies that the existence of the relationship is dependent on the order in which the two elements are considered (IMD).

DISCOUNT FACTOR. A fraction between 0 and 1 which gives the present worth of one monetary unit spent or received (DIS).

DISCOUNT RATE. A percentage rate (usually annual) which equates the present and the future worth of a payment (DIS).

DISCOUNTED CASH FLOW. A single value which represents the present worth of the net incremental benefits estimated for each project year (NPW).

DISCRETE STOCHASTIC MODEL. A model which describes the changes in variables at definite points in time (CSM).

DISCRETE VARIABLE. A variable with only a finite number of values which are multiples of a basic unit (HIS).

DRIVING FORCE. An attribute of a system which causes changes in the system state over time (SCN).

DUNNING. The process for recontacting participants who have failed to return their questionnaires (DLP).

DURATION. The estimated time needed to perform the activity (CPM).

DYNAMIC BEHAVIOR. A consequence of delayed interactions among system variables. The dynamic state of a system depends on the prior values of state variables (OBT, RTS).

EARLIEST FINISH (EF). The sum of an activity's earliest start time and its duration (CPM).

EARLIEST START (ES). The earliest time (measured from the start of the project) when an activity may begin, assuming all immediate predecessors are completed (CPM).

ECONOMIC ANALYSIS. Analysis from the viewpoint of the national government and the economy (CFA).

EFFECTIVENESS. The degree to which the project or system design objectives are achieved (CEA).

ELEMENT. Part of a problem situation which can be described by all its elements (MPA).

ELSE RULE. A column in a decision table which applies when no other decision rules may be added to cover the case or where no combination of conditions applies (DTB).

ENVIRONMENT. The set of all factors which are salient to the understanding of systems relationships, but which are outside the influence of the system variables (OBT, SDM).

EVENT. A future outcome, the occurrence of which is uncertain (SPA).

EXTERNAL CONTEXT. Represents the constraints on the base system (SCN).

FANTASY ANALOGY. The participant's wishful thinking that the problem may solve itself or cease to exist (SYN).

FEEDBACK STRUCTURE. The set of relationships describing a system that involves one or more interlocking causal loops (OVD).

FINANCIAL ANALYSIS. Analysis from the viewpoint of the individual, group, or business which will directly gain or lose because of the project (CFA).

FREQUENCY DISTRIBUTION. Plots the frequency of different categories of response (QTN).

FUNCTION. The primary concern of the system. It is the fundamental dimension of purpose (FEX, IDL, SDM).

FUNCTION HIERARCHY. An ordering of system functions from the most specific to the broadest (FEX).

FUNDAMENTAL DIMENSION. The basic characteristic of the eight system elements (SDM).

GOAL. A value judgment which satisfies one or more needs (FEX, LGF, SCN).

GOVERNING RULES. Describe the relationships between decisions made by the participants in a game and the resulting changes in the simulated environment (GAM).

HIERARCHY. An ordered structure illustrating which factors are subordinate to others (TRD).

HUMAN AGENTS. The personnel who may be necessary for the system to achieve its function, yet are not themselves inputs or outputs of the system (SDM).

IDEAL SYSTEM. A system that achieves the function in the best possible manner as judged by the criteria for evaluating the system. Such systems typically require the least possible cost, the least amount of human resources, and the least time while providing maximum benefits (IDL).

IMMEDIATE PREDECESSOR. Any activity which immediately precedes an activity and which must be completed before the activity can start (CPM).

IMMEDIATE SUCCESSOR. Any activity which immediately follows an activity and which may not start until completion of the activity (CPM).

IMPORTANT ASSUMPTIONS. The factors which affect the success of a project and which are beyond the influence of the decision maker (LGF).

INCREMENTAL COSTS AND BENEFITS. Computed by subtracting the "without project" values from the "with project" values (CFA).

INDEPENDENT VARIABLE. The non-random variable which is used for forecasting other variables using regression (RGF).

INFLUENCE RELATIONSHIP. When one variable's change in value influences change in another variable (TRD).

INFLUENCE TREE. A tree that diagrams the variables which influence other variables which are higher in the tree (TRD).

INFORMATION CATALYSTS. The communication (written or verbal) and the knowledge which enable the system process to occur, yet which are not inputs or outputs of the system (SDM).

INPUTS. The people, information, and/or physical items which enter the system to be transformed by a sequence into outputs of the system (LGF, SDM).

INTERACTING GROUP. A process that permits discussion among participants (NGT).

INTERFACE DIMENSION. The relation to other systems or elements—a linking entry to related system definition matrices (SDM).

INTERMEDIATE IMAGE. An intermediate image describes the state of the system after a time interval *n* (SCN).

INTERNAL ECONOMIC RETURN. The rate of return derived from an economic analysis of the benefits and costs to the society or economy of the country (IRR).

INTERNAL FINANCIAL RETURN. The rate of return derived from a financial analysis of the project cash flow (IRR).

INTERVAL SCALES. Scales that reflect not only the rank of one factor over another, but the degree to which one exceeds the other. The difference between them corresponds to a length of scale interval (RTS).

INTERVIEW SCHEDULE. The plan for conducting an interview. It includes the questions to be asked (IVW).

INVERTED EFFECT. An interaction between two variables so that a change in one results in an opposite change in the other (OVD).

IRREVERSIBLE VARIABLE INTERACTION. When the variable only increases or only decreases (OVD).

LATEST FINISH (LF). The latest time (measured from the start of the project) when an activity may be completed without delaying any immediate successor(s), thereby delaying completion of the project (CPM).

LATEST START (LS). An activity's latest finish time minus its duration (CPM).

LIMITED ENTRY. A type of decision table which permits only a limited set of condition and action entries in the decision rule columns (DTB).

LINEARLY LINKED MATRICES. Matrices with a common set of rows or columns (IMD).

LOGIC ELEMENT. A symbol indicating the nature of the relationship between two or more objectives at adjacent levels in a hierarchy (INS).

LOGICAL INCONSISTENCIES. When hypothesized relationships among variables are inconsistent (OVD).

LOGICAL MEASUREMENT. Determines whether a binary-event objective has or has not occurred (OBT).

MATRIX. A mathematical and graphical representation in two dimensions (IMD).

MATRIX ENTRY. The symbol used to indicate the existence or absence of a relationship between the element in the row and the element in the column (which together define the entry) (IMD).

MEAN. The average value or central tendency of the data (HIS).

MEANS OF VERIFICATION. The specific mechanisms by which quantitative indications of the accomplishment of a project may be observed (LCE).

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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