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9. ABSTRACT

Part II of the Agricultural Sector Planning report argues that it is possible to develop decision making systems that include and investigative capacity to carry out analytical and monitoring functions with computer based models as an integral part of the system. Agricultural decision makers and development analysts have turned toward a more comprehensive and systematic view, which has become known as the sector analysis approach. Solving agricultural sector development problems requires a broad system perspective and a generalized analysis. The necessary resources must be made available, the necessary institutional frameworks developed, and the necessary coordination provided to ensure improved decision making and successful results. The basis and approach for improving the quality of decision making discussed in this report are in the context of agricultural sector development planning and policy formulation. The approach discussed is completely generalizable to other sectors of the economy and other aspects of the socioeconomic system. The process leading to models that can play a useful role in agricultural sector decision making are discussed in detail. Ill-conceived models can waste scarce resources and contribute little to the decision making process. The key is a skilled and experienced model development team institutionalized as part of the decision structure.

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AGRICULTURAL SECTOR PLANNING

A GENERAL SYSTEM SIMULATION APPROACH

EDITED BY GEORGE E. ROSSMILLER

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PREFACE

For as long as governments have existed, public sector decision makers have searched for better methods of planning and monitoring the performance of national economies and their subcomponents. In recent years, interest in many countries has focused on comprehensive and integrated sectoral planning and performance monitoring. Government officials in these countries are searching for better tools and techniques to assure more consistent and higher quality analytic input into their decisions. Some have turned to computer-based models as a partial answer to their needs. Many, however, are reluctant to make the sizable investment required for large and complex computer-based modeling efforts.

The arguments against computer-based modeling largely follow the line that the techniques and methodologies employed are generally not understood by decision makers, often do not include all the information necessary to a comprehensive analysis of the problem under consideration, and sometimes lead to unworkable prescriptions for action. Such arguments, in too many cases, have been justified.

The authors contributing to this book argue that it is possible, and in many cases highly desirable, to develop decision-making systems that include an investigative capacity to carry out analytical and monitoring functions with computer-based models as an integral part of the system. The authors, with widely varying backgrounds and experiences, through a series of fortuitous events became involved in working together on a project funded by the U.S. Agency for International Development (USAID) and carried out by Michigan State University in cooperation with the Ministry of Agriculture and Fisheries, Republic of Korea. This book is about the set of experiences and the lessons learned from this project. As such, it is as much about people and institutions as it is about models. The book should be useful to a wide range of scholars, students, administrators, policy analysts, planners, and decision makers interested in better approaches to more effective public sector decision making.

Although the work in Korea is depicted in some detail, the auth intend these descriptions to be viewed by the reader as a case example the application of the general system simulation approach toward provi ing investigative input into the decision process. The Korea exam focuses on national-level decision making with respect to agricultu sector development. But the lessons learned from this experience and t conceptual framework of the approach are applicable in a variety decision-making contexts, subject matter foci, and geographic locatior

We wish to acknowledge the contributions and support provided Francis C. Jones, both as project monitor during his tenure as Food a Agriculture Officer, USAID/Korea, and as one of the authors of this bo after his retirement from USAID. His death in the spring of 1977 sadden us all.

It is impossible to individually acknowledge the contributions by t many people and institutions who have been a part of the projects up which this book is based. To them the authors of this book owe a heartf debt of gratitude. Special acknowledgment and appreciation are due t institutions with which the authors are affiliated for providing them t opportunity to participate. We also specifically acknowledge the Gove ment of the Republic of Korea for its contributions and cooperation, a the U.S. Agency for International Development for the funding whi made both the projects and the book possible.

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George E. Rossmil
Editor for the Te

Michigan State University
January 1978

INTRODUCTION

The purpose of this volume is to explain the general system simulation approach as a viable basis for providing input to planning and policy decision making in agricultural sector development. We do this through discussion of the philosophic orientation of the approach, its eclecticism with respect to modeling techniques and types and sources of data, its relationship to the decision-making process, and the establishment of its credibility with decision makers. We also discuss the prerequisites for institutionalization and use of the general system simulation approach for agricultural sector development planning and policy analysis within the agricultural decision structure of a national government. The development and institutionalization of the approach in Korea is detailed and conclusions are drawn about its transferability and preconditions for its use in other developing (or developed) countries.

A wide and varied audience for this volume is anticipated. It should be of particular interest to:

1. Agricultural sector development decision makers at the national level interested in improving the quality of their planning, policy formulation, program development, and project design, implementation, and evaluation
2. Agricultural sector development staff and policy analysts searching for more useful and comprehensive approaches to problem-solving analysis
3. Students of the systems approach interested in methodology and application of systems analysis to socioeconomic problem areas

4. Students of economic development within and outside the acaden community who are interested in alternative methodological a proaches to agricultural sector development problem solving
5. Students of political and institutional development interested in t problems, requirements, and process of integrating the use of qua titative analysis into the decision-making structure of developing developed) countries

In writing for such a diverse audience, we run the risk of probing t deeply in some areas and not deeply enough in others to satisfy any giv reader. For those of you who are quantitatively oriented and are interest in a more in-depth mathematical treatment of the models, we can or refer you to the technical documentation by the project team [1, 2, 8, 3 40, 115]. We urge those who find some of the concepts and the occasior mathematical exposition to be laborious simply to skip over those sectic or equations. In doing so, most readers will find the general meaning s apparent.

The book is organized into five parts. Part I, "The Case Study Project consists of chapter 1 and covers the development of the projects and t experience upon which this book is based. Part II, "The General Syste Simulation Approach," consists of three chapters. The first, chapter presents the conceptual framework of the general system simulation a proach to improved decision making. The description focuses on a r tional decision structure concerned with agricultural sector developme The second, chapter 3, develops the public policy environment with which the agricultural sector operates and the policy choices available the agricultural decision maker as influenced by the prevailing val system imposed by the socioeconomic, technical, and political enviro ment. The third, chapter 4, covers a wide spectrum of model types a techniques, describes how they are used in decision analysis, and indicat their strengths and weaknesses.

Part III, "The Korean Agricultural Sector Models," consists of 9 cha ters. The first, chapter 5, describes the process of sector model conce tualization in Korea. The next five, chapters 6 through 10, describe cor ponent models that constitute the Korean agricultural sector model syste and give illustrations of their application for planning and policy analy purposes. The five component models in the Korean agricultural sec model system are population, national economy, technology chan resource allocation and production, and demand-price-trade. The ne chapter 11, discusses data and parameter estimate requirements for t model and how they were obtained. The final two chapters in this p indicate the process by which the models can be used by decision mak

(chapter 12) and a specific application of the models in long-term planning for land and water development (chapter 13).

Part IV, "The Korean Grain Subsector Models," illustrates the two subsector models built to focus specifically on short- and medium-term problems associated with the Korean government's grain management program. The first, chapter 14, discusses the grain management program model, developed for use as an on-line management tool for government decisions regarding the price, stock, storage, and trade of grain. The second, chapter 15, illustrates a small, static model used to analyze the consequences of grain pricing decisions on production, consumption, inflation, foreign exchange, and government grain management accounts.

Part V, "Technology Transfer," consists of four chapters that cover the problems, requirements, and process of integrating the use of quantitative analysis into the decision-making structure of developing countries. The first, chapter 16, discusses the requirements and prerequisites for institutionalization of the general system simulation approach into a national agricultural decision framework, and the second, chapter 17, indicates the amount and kind of training for indigenous personnel necessary to institutionalize the approach effectively. The third, chapter 18, illustrates the generalizations indicated in the previous two chapters through the experience in Korea, and the last, chapter 19, discusses the future directions necessary to further develop the approach in Korea, as well as to transfer the general approach to other developing (or developed) countries, subject matter areas, and problems.

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PART TWO

THE GENERAL SYSTEM SIMULATION APPROACH

2
IMPROVING AGRICULTURAL DECISION MAKING: A CONCEPTUAL FRAMEWORK

Glenn L. Johnson
George E. Rossmiller

INTRODUCTION

Planning and policy decision making are recognized as necessary and legitimate activities of governments throughout the world [74]. As socioeconomic linkages and interdependencies become more complex within and between nations, planning and policy determination become increasingly important functions of national governments. With limited resources available to achieve development goals, enlightened decision making by governments in carrying out these functions is imperative.

During the past decade agricultural decision makers and development analysts, in their search for new and better means of agricultural development, have turned toward a more comprehensive and systematic view, which has become known as the sector analysis approach. This new approach arose from dissatisfaction with other, more limited analytical approaches and the increasing recognition that agricultural sector development is comprised of literally thousands of separate, but interrelated, problems. For example, In many developing agricultural economies, population and rising incomes are straining the capacity of limited agricultural resources and traditional agricultural production techniques to increase and adapt food production to demands. Food prices are high, and farm incomes are low. Scarce foreign exchange is often used for increasing importation of food commodities. Diets lack sufficient protein, particularly animal protein. Labor is moving out of agriculture through farm-to-nonfarm migration. Agricultural credit is in short supply. Marketing sys-

tems, transportation, and communication networks are inadequate to serve a commercializing agriculture and an urbanizing economy. Inequitable ownership of productive resources and, hence, inequitable income distributions are found within agriculture, within the nonagricultural sectors, between sectors, and among regions [151]. Administrative and institutional constraints in the agricultural establishment limit the capacity of government to deal effectively with the problems of agricultural sector development [12]. The list could continue almost without limit, but it is already sufficiently long to illustrate the point that the problems are complex and interrelated and that solutions are certain to cause both desirable and undesirable consequences.

Solving agricultural sector development problems, therefore, requires a broad system perspective and a generalized analysis. The necessary resources must be made available, the necessary institutional frameworks developed, and the necessary coordination provided to ensure improved decision making and successful results. The basis and approach for improving the quality of decision making discussed in this book are in the context of agricultural sector development planning and policy formulation [85, 151]. The approach discussed here is completely generalizable to other sectors of the economy and other aspects of the socioeconomic system.

ROLE OF THE DECISION MAKER

The role of the decision maker in the public sector is to develop consistent sets of plans, policies, programs, and projects to achieve a consistent set of goals based upon national values [151]. Governmental decision makers must solve immediate problems, avert contemplated future problems, and confront issues which if left unattended may become problems. The decision maker, then, is primarily a problem solver.

Planning activities in various countries range from elementary and ad hoc responses to ongoing events to extremely detailed and carefully conceptualized long-term plans. The major objective of planning is to allocate public sector funds among governmental ministries and within ministries to programs and projects designed to meet the specified goals. In a mixed economy public decision makers must give attention to the effect of public decisions on the actions of private decision makers. In any planning process, assumptions must be made about changes and trends in the environment that will affect the activity and behavior of the system being planned. Assumptions and theoretical concepts are necessary to project the consequences for the system of alternative plan strategies. Policies are developed and implemented and planning strategies adjusted over time to affect system performance in desirable ways as both the system and its environment change. The more the planner and policy decision maker

know about the system and its environment and the way the system will respond to both external and internal stimuli, the better they can do their jobs.

In recent years a mechanism adopted by many developing countries to formalize the governmental role in planning for economic development has been the four- or five-year economic development plan. In most cases a central planning agency is established, either as a super ministry or as a direct arm of the executive branch, with authority to establish development goals and guidelines and to coordinate the planning activities of the individual functional ministries. A successful development plan requires a highly integrated and coordinated planning activity in which national values are well established and understood, realistic targets are clearly specified, budgets are allocated commensurate with the prescribed goals, and policies, programs, and projects are developed and implemented in a timely and consistent manner to fulfill the plan. Unfortunately, only in extremely rare instances are all these requirements fulfilled, especially in developing countries.

Frequently the public sector decision maker has little reliable data, information, or analysis at his disposal for decision making. In many countries the decision-making role is vested in personnel who are rotated frequently among administrative posts. Often the civil servant staffs are neither well trained nor highly motivated. Thus, little institutional experience is built from which to draw an historical perspective in carrying out the decision-making role. Unless this body of past experience is organized in a useful way, it is difficult for decision makers and their staffs to draw conclusions about the present state of affairs and to project the consequences of alternative courses of action into the future. In the absence of such a perspective a great deal of ad hoc decision making is done within a very narrow time perspective. The decision maker often finds his time and energy consumed by the need to handle unanticipated current problems, often the consequences of past ill-conceived decisions based on incomplete information and inadequate analysis. This situation is depicted in Figure 2, which shows the decision maker operating with a very narrow perspective on time and at a very high level of short-term crisis activity. The decision maker in this case has little experience and historical perspective on the one hand, and little sense of the intermediate and long-range future on the other.

Decision makers can be better equipped to broaden their perspective of time, as shown in Figure 3 [61, 64, 84, 94, 119, 125, 154, 168]. Historical experience can be organized into an easily accessible data and information system. Formal analytical frameworks then can be developed to use that information and data in learning more about *future expec-*

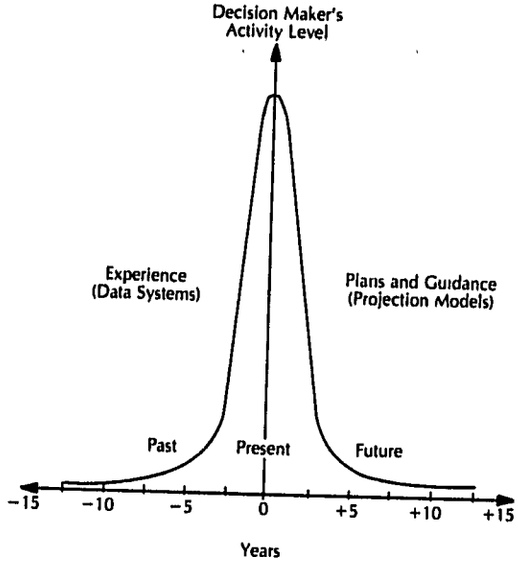

FIG. 2. Common orientation of a decision maker to time.

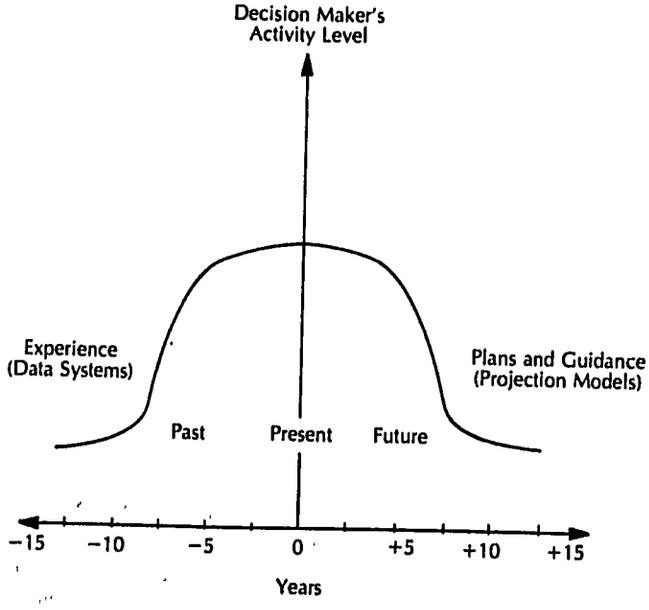

FIG. 3. Improved orientation of a decision maker to time.

tations and in *projecting the consequences* of alternative planning strategies, policies, and programs of action. A longer time perspective on both the past and the future, as well as a lower profile of activity concerned with the immediate present can thus be attained. A major portion of the rest of this book is devoted to discussion of how the time orientation shown in Figure 3 can be accomplished.

A NATIONAL AGRICULTURAL DECISION-MAKING CAPACITY

The total capacity of a country for solving agrarian problems can be indicated by a circle, such as that in Figure 4. In turn, that capacity can be divided into two parts: (1) the investigative function, which is the capacity to acquire, analyze, and synthesize information; and (2) the administrative function (including all bases of power), which is the capacity to make and execute decisions and bear responsibility for consequences of action taken. The term *investigative* is used throughout this book in the research sense of systematic inquiry and refers to the three broad functions of acquisition, analysis, and synthesis of information. As used here, the term has no law enforcement connotation.

FIG. 4. National agricultural decision-making capacity.

Although a clear distinction can be made between the investigative and administrative *functions,* the distinction between *investigators* and *administrators* is often not as easy to make and, for that matter, not entirely necessary for our purposes. It is sufficient that, in carrying out the problem-solving decision process, the responsibility and authority for each of the functions be vested in the individuals engaged in carrying them out. The mix of functional responsibility and authority varies, depending on organizational structure and the specific problem involved.

Administrative and Investigative Capacity and Functions

The administrative capacity dealing with agriculture rests in the administrative and decision-making personnel involved in the decisions, action, and responsibility-bearing functions of planning, policy formulation, program development, and project design, execution, and evaluation that have an impact on the agricultural sector. Many such personnel will be found within the organizational structure of the government agency concerned specifically with the agricultural sector and its problems; this agency is often known as the agricultural ministry [12]. Other such personnel may be found in a central planning agency or, in other ministries having responsibilities that affect agriculture — such as transportation, health, education, and finance. Still others will be found in the chief executive office, subadministrative units such as provincial and village governments, and other organizations vested with the power to influence the course and development of the agricultural sector.

The main functions of personnel in the administrative capacity include participating with those in the investigative capacity in problem definition, as well as decision making, execution or action taking, and responsibility bearing [12, 84]. The ability of any administrative or decision-making unit in the administrative capacity to solve specific problems depends on (1) the unit having authority to decide and act over the domain within which the problem falls; (2) the ability of that unit to execute sound decisions; and (3) the power of other administrative units and affected persons to react to the possible and actual consequences of those decisions and actions. Power is expressed in covenants that have to do with property ownership (market power), political alliances, military and police control, intellectual and moral leadership, and the influence of the press. The feedback of information from action takers and affected persons to decision makers is at least as important in solving problems as the input to the process from problem-oriented investigators.

A substantial proportion of a nation's investigative capacity vis-à-vis agriculture resides with the personnel manning its research and analysis agencies and in the academic community that feeds disciplinary knowledge to the analysts. Among the other resources included in a country's investigative capacity are subject-matter models and associated general-purpose data systems. The main problem-solving functions performed by those in the investigative capacity are observation, analysis, and synthesis, although obviously specific investigative units often include their own administration and at times furnish people to serve on the administrative side. Important contributing functions include developing new disciplinary knowledge, combining disciplinary and descriptive knowledge into

subject-matter models, and acquiring and storing descriptive data and information.

A distinction is necessary between various types of research and analysis found in a country's investigative capacity, since different types are carried out for quite different purposes. Further, this distinction is necessary for understanding how the various components of the investigative capacity interact with those in the administrative capacity for problem-solving decision making.

Types of Supporting Research and Models

Three distinct types of research and models can be found in the investigative capacity of a country: disciplinary, subject-matter, and problem-solving [74].

Disciplinary Research and Models. Disciplinary departments of a nation's colleges and universities, such as agricultural economics, political science, public administration, and life and physical sciences, are a part of its investigative capacity with respect to agrarian problems, but they also function partly outside of that capacity [74]. The purpose of disciplinary research and model development is normally the further extension of disciplinary theoretical knowledge and/or further disciplinary methodological development. Such research and model development may be of relevance to solving practical problems; but, in some cases, it may be of unknown relevance [72]. Practical problem solving is not an immediate objective of disciplinary work, mainly because few, if any, problems lie within the domain of a single discipline.

If the models of, say, an hydrologist, a plant geneticist, an economist, or a political scientist are immediately useful as components in building subject-matter or problem-solving models, they are relevant. If they are not immediately useful for these purposes, they are of unknown relevance, at least insofar as the specific problem or set of problems under consideration is concerned.

In Figure 5, for example, economics is diagrammed as Discipline 1, and soil science is diagrammed as Discipline 2. Both disciplines contribute to, but also extend outside of the investigative capacity because they cover research of unknown relevance and include teaching responsibilities. Of course, many other disciplines could also be included in this diagram.

Because disciplinary models can be relevant, disciplinarians often regard their models as problem solving, even though their models are inadequate for handling the entire domain of any specific problem [78]. When this occurs, major credibility problems quickly arise between the disciplinarians and the decision makers [71]. Similarly, subject-matter and problem-solving research often are discredited by the disciplinarian who

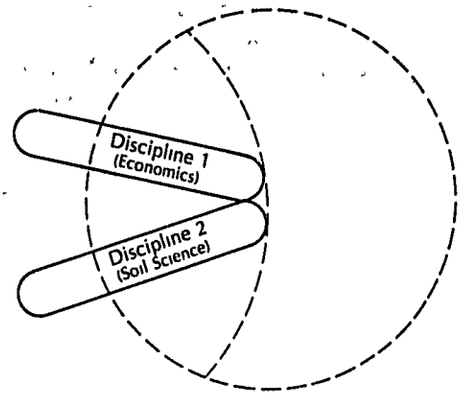

FIG. 5. The relationship of sample disciplines to the national agricultural decision-making capacity.

concentrates on the disciplinary information and conceptualization in these models but who "sells" his results as problem solving [71, 81]. The disciplinarian is likely to be offended by the multidisciplinary balance that must be achieved to develop models of relevance to problem solution [77].

Despite the dangers of misunderstandings and the shortcomings inherent in disciplinary research with respect to problem solving, the basic disciplines create the necessary components, models, conceptualizations, and techniques for subject-matter researchers and problem solvers [76, 141]. Disciplinarians also provide the trained manpower to use the information, models, and techniques in building subject-matter models and in solving problems.

Subject-Matter Research and Models. Subject-matter research and models develop knowledge about an area of concern, such as agricultural sector development, land tenure, world food production and consumption, national transportation needs, or world energy requirements [71]. They are multidisciplinary and can provide information useful to the solution of *sets* of practical problems within the specific area of concern. That is, each subject-matter area of concern contains many specific, interrelated problems requiring a given kind of knowledge from a variety of disciplines for their solution. However, any specific problem within the problem set typically requires additional information of other kinds and from other sources for its solution. Subject-matter research and models are also specific to the set of decision-making units responsible for solving specific sets of problems.

Subject-matter models or logical frameworks are important because they bring together bodies of knowledge — including data, information, theory, and methodology — that match a set of important problems and that can make a significant contribution to the solution of specific problems within the set. It is important to note that subject-matter models are not problem specific. Additional information, modeling, and analysis will need to be done to solve specific problems, and at the same time all information in the subject-matter model may not be used. Again, credibility may suffer, if subject-matter modelers and analysts attempt to sell their subject-matter work to decision makers as problem solving.

Along with, or as part of, subject-matter models are general-purpose data and information systems [21]. The data and information from these systems derive their meaning in large part from the subject-matter models they accompany. A common example is the agricultural accounts model of a nation which is built around various concepts of input, output, distributive shares, industries, technology, political subdivision, institutions, human behavior, and so forth. National agricultural account models and information systems are seldom capable in and of themselves of providing everything needed to solve a specific problem. Yet they make such significant contributions to the solutions of a broad spectrum of problems that most nations maintain such models and associated information systems. Model 1 in Figure 6 represents a national agricultural accounts model and associated information system. A general subject-matter model of the agricultural sector is represented in this same figure as Model 2 [85, 127, 151]. The two models may overlap in part, as shown, but the sector model may include much detail in agriculture not found in the national agricul-

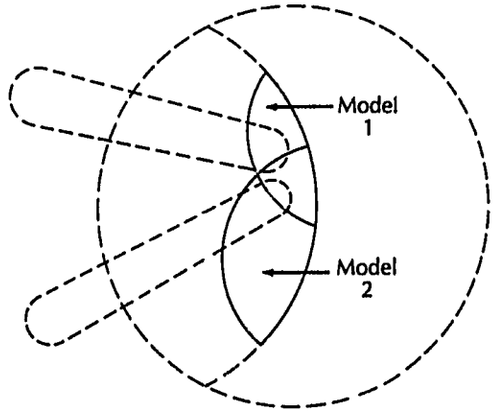

FIG. 6. The relationship of models to the national agricultural decision-making capacity.

tural account model and, as such, can address a different and larger spectrum of problems.

Problem-Solving Models and Processes. Problem-solving models and analyses are problem specific and obtain credibility when they solve the problem for which they were created [84, 87, 93]. Like subject-matter models, they are multidisciplinary but they are specific to a problem and to a decision-making unit. Such models typically include decision makers, executives, and affected persons as sources of information, in addition to researchers and analysts. A specific problem, Problem I in Figure 7, has a domain that crosses both the investigative and administrative sides in the figure.

Usually, practical problems have domains involving several different disciplines and require the use of knowledge and information from one or more of the disciplinary and subject-matter models available in the country's investigative capacity [74]. Typically, additional problem-specific information and modeling are necessary to contribute to the solution of the specific problem. The output from a problem-solving model is a prescription for action. A problem-solving model can lose credibility with decision makers if its prescription is based on inadequate or inappropriate information and knowledge [71, 81].

Types of Research and Models Compared. Major controversies can arise among disciplinarians, subject-matter researchers, and problem solvers when one attempts to evaluate the work of the other [71]. They have different criteria in mind for their evaluations, since they have different purposes at the onset. The purpose of the disciplinarian is to improve

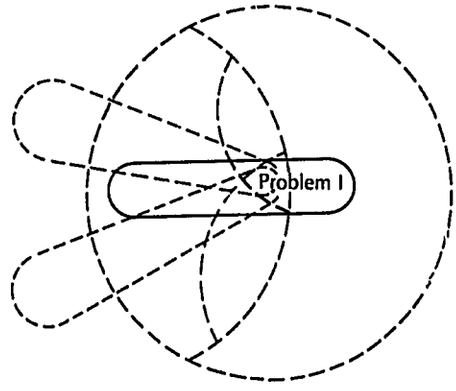

FIG. 7. The relationship of problems to the national agricultural decision-making capacity.

the theory, data, and methodology relating to the discipline. His criterion for evaluating research and models is whether they contribute to improvement and expansion of disciplinary knowledge. The problem solver is concerned that the results of his research and models contribute to the solution of specific problems. The determination of the consequences of decisions and actions on affected persons, the ability to execute decisions given the reality of the situation, and the distributions of power among participants are important to him. Subject-matter researchers and modelers have purposes and criteria falling between the disciplinarian and the problem solver. They are concerned with contributing to the stock of knowledge in a subject area. This knowledge can be useful in contributing to the solution of sets of problems within the subject-matter area, but only rarely can specific problems be solved without additional knowledge, data analysis, and synthesis. Thus the solution of specific problems and the concern for decision execution and power distributions are not included in the subject-matter researcher's evaluative criteria.

THE DECISION-MAKING PROCESS FOR PROBLEM SOLVING

Since a problem's solution requires decisions that are the results of the interactions of participants from both the investigative and the administrative sides of the country's decision-making capacity, a detailed discussion of the decision-making process is in order [13, 22, 42, 43, 44, 53, 57, 58, 61, 64, 75, 84, 94, 121, 125, 154, 168, 173, 175]. Decision-making theoreticians and practitioners depict the steps in the decision-making process in varied but similar ways. One such view is depicted in Figure 8 as a sequential and iterative set of six steps, including (1) definition of the problem, (2) observation and collection of data and information, (3) analysis and synthesis to determine the consequences of alternative courses of action, (4) decision upon a course of action, (5) execution or action to implement the decision, and (6) responsibility bearing, which includes monitoring and evaluation of the results and feedback of those results into the decision process. The process is continuous and iterative in that the results of the decisions and actions must be constantly evaluated, issues redefined, observations extended, analysis reappraised, and decisions and actions adjusted accordingly in the light of new experience, new knowledge, and changing conditions.

Problem definition, the first function in the decision-making process, falls in both the investigative and administrative capacities as shown in Figure 7 [74, 84]. Observation and analysis (functions 2 and 3 of the decision-making process) fall mainly in the investigative capacity, whereas decision making, action, and responsibility bearing (functions 4, 5, and 6

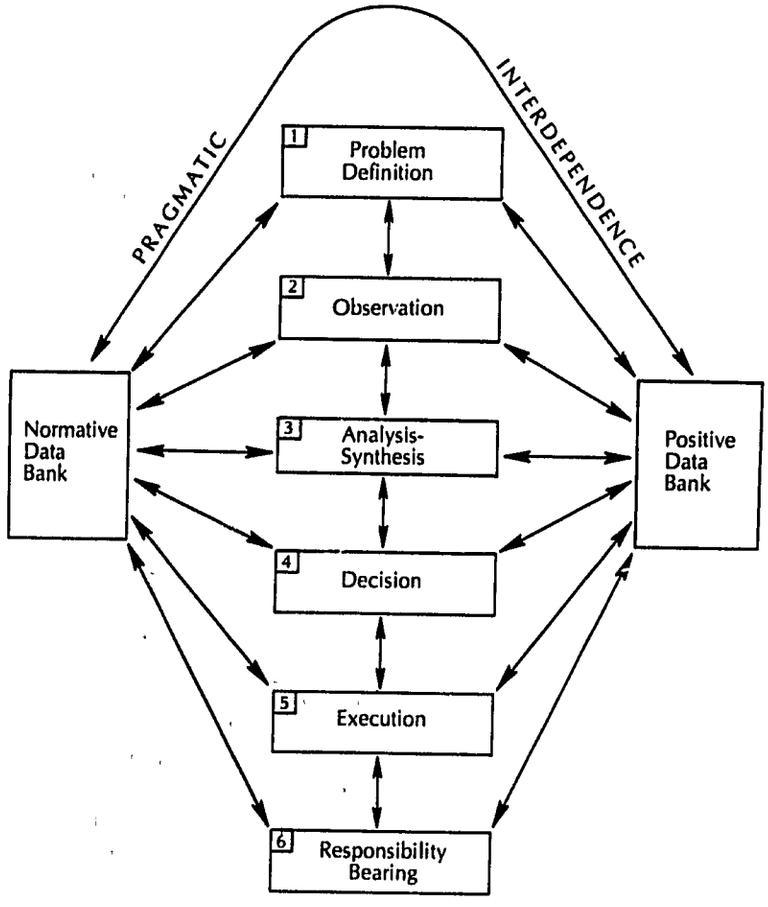

FIG. 8. The decision-making process.

of the decision-making process) fall mainly in the administrative capacity. Problem definition involves the conviction that a situation can be improved within the purview of a decision-making unit.

A problem domain, such as Problem I (Fig. 7), is specific to a decision-making unit that has the power to decide and act while being required to bear responsibility [74]. On the investigative side, individual disciplines make their own special contributions to understanding the technical, institutional, and humanistic aspects of a problem. Problem definition will often require drawing on parts of more than one subject-matter model and, in addition, will usually require ad hoc conceptualization not existing as part of any established subject-matter model.

The second function in the decision-making process is observation, which includes collecting and processing data and information [21, 84]. Broadly speaking, institutional, technological, and human information about the past, present, and future are likely to be required [74, 84]. Expectations and how they are formed are important [64, 74, 84, 119]. Normally, much data and information, both normative and positive, are available in published form, in data banks, or in existing models. Often, however, primary data must be collected for a specific problem through the use of surveys, experiments, or solicitation of the judgment of knowledgeable people. The administrative side of a nation's decision-making capacity, including the feedback channels from affected persons, is often an important source of data and information. Another important feedback channel is the market, which sends a variety of messages to decision makers about supplies, demands, prices, and other important variables. Another is the political system. For these latter channels to be effective, affected people must have power to originate and convey messages.

What data should be collected and in what detail should be determined by equating the marginal costs of each kind of information with its marginal value in the context of the problem being solved Because the world is infinitely detailed, whereas budgets are finite and time is limited, attention must be concentrated on the most important data [74, 84]. Disciplinary interests, subject-matter considerations, and personal penchants for a particular kind of data should give way to the opportunity cost principle in allocating observation to the different parts of a problem domain.

The third function is analysis and synthesis [84]. Occasionally, strictly disciplinary models and empirical work can contribute to problem solution. Subject-matter models, such as agricultural sector models and national agricultural accounts, often provide components useful in modeling or conceptualizing the domains of a particular problem. Other components are typically created *in situ* or are "borrowed" from other subject-matter models. Data, information, and model components, as well as talent, often can be obtained from academicians, consultants, and advisers not normally part of the particular investigative unit. In addition, important and useful data and information can be received from the decision makers themselves. Economizing is necessary in conceptualizing the domain of a problem. Optimal degrees of refinement can be defined by equating costs and returns at the margin for different components in the context of the specific problem being solved.

The fourth function in problem solving is decision [84, 85]. In this function the analysis and synthesis of the relevant theories, data, and information are translated into a prescription for action to solve the specific problem at hand. The decision may maximize, in the sense that it might

indicate which open course of action is "the best" or, perhaps, "the least bad" to take [121]. The formal analytical components of the problem-solving model need not contain a maximization component, particularly if the decision maker is willing to serve in that capacity as part of the total model. Even when the model of a problem domain has a maximizing component, the real decision maker is likely to reserve the right to override the dictates of such a component in making his decision.

The fifth function in problem-solving decision making is action or execution [12, 84]. The ability of the decision maker to implement his decisions affects the detail with which it pays to model or conceptualize a problem and its solution. A so-called solution that cannot be implemented is not a solution.

The sixth and final function in the problem-solving process is responsibility bearing [84]. Responsibility is borne by decision makers, action takers, and affected people. Those who bear the consequences of actions may have power to originate and transmit feedback messages and to participate in decision making. The extent to which decision makers bear responsibility, monitor consequences, and are required to receive feedback messages partially determines their participation in observation and analysis of the domain of a problem and in deciding upon its solution.

Normative, Positive, and Prescriptive Knowledge

Throughout the decision process both normative [121, 135, 152] and positive knowledge must be collected and combined into prescriptive knowledge on the basis of some decision rule to establish goals (about future actions) or to determine the right actions (in the present) [83, 121, 124]. Several of the terms in this statement are used throughout the remainder of the text with precise meanings. To avoid ambiguity, these terms must be defined.

Normative knowledge deals with concepts of value [52, 124]. It pertains to the goodness and badness per se of a condition, situation, or thing. A concept of goodness exists when a condition, situation, or thing is perceived on the basis of experience and logic to contribute to the attainment of human interests and purposes [135]. Conversely, a concept of badness exists when a condition, situation, or thing is perceived on the basis of experience and logic to frustrate or detract from the attainment of human interests and purposes. A shorthand means of indicating values is to refer to *goods* to be attained and *bads* to be avoided.

Decision makers deal with both monetary and nonmonetary values in a socioeconomic context [13, 73, 79, 84, 121, 123]. Economics is concerned with attainment of nonmonetary as well as monetary values. The

error of treating nonmonetary values as noneconomic, for example; would eliminate consumption and welfare economics from economics. It is difficult to conceive of a single value about which efficiency considerations do not arise when one is trying to attain it (if it is good) or avoid it (if it is bad). It is equally difficult to think of a purely economic or a purely social value. Attainment of economic values is attended by social consequences; and, conversely, considerations of efficiency (economic) are involved in attaining or avoiding social values. Thus, there is no dichotomy between economic and social values.

Nonnormative, or positive knowledge, is information about a condition, situation, or thing not pertaining to its goodness or badness. The term *nonnormative* is used as a synonym for the term *positive* to highlight a rejection of the positivistic notion that normative facts, truths, and experiences do not exist [52]. In this light, both normative and positive facts exist and the fact-value dichotomy is rejected. Nonnormative or positive knowledge is usually thought of as pertaining to the physical and biological or "hard" sciences; however, such knowledge is also found in the social sciences — for example, census data contain information about numbers of people, with no connotation of goodness or badness.

Prescriptive knowledge in the solution of a specific problem is generated by relating the positive to the normative. Pragmatism is concerned with prescriptive knowledge — skills, recipes, rules of conduct, law — for the solution of problems. Philosophically, pragmatism is based on the metaphysical presupposition that normative and positive truths are interdependent and that workability is a test of the truth of a concept [54, 55, 140, 153]. Thus, the pragmatic interaction loop between the two data banks in Figure 8 represents, in one sense, the skills, recipes, rules, and laws available for problem-solving decision making and, in another sense, the pragmatic assertion that normative truth and nonnormative truth depend mutually on each other.

Both normative and positive knowledge are necessary and must be used together to reach prescriptive knowledge to define and solve practical problems with appropriate actions. Prescriptive knowledge pertains to "what ought to be" and how "what ought to be" ought to be accomplished [13, 73, 84, 121].

A prescription describes a right action [121]. The concepts of right and wrong depend both on normative and positive concepts about past, present, and future. Thus, it may be wrong to do what is good because something better might be possible. Conversely, it may be right to do something bad if it is the least bad that can be done. It should be clear from the discussion and Figure 8 that the decision-making process is prescriptive and that normative and positive knowledge are the two supports upon

which the decision-making process rests; the absence of either causes the process to fail.

Prescriptive knowledge is difficult and often uneconomic to bank because of the specificity of problems. When a problem occurs repeatedly and can be solved by a rule, the prescription becomes something of a skill, a recipe, or law-governing action. Skills can be banked in decision makers, executives, foremen, supervisors, and analysts. Recipes can be written out as instructions to be followed. Laws can be promulgated. Skills, recipes, and laws are relative to both values and positive information about what is possible.

The task of the decision maker is to maximize the positive difference between good and bad. Right actions are constrained by what is feasible in reality. A simple illustration of prescription is one in which the problem is to determine the "right" amount of nitrogen to apply and the "right" yield of corn to attain. The positive production function relating corn yield to nitrogen applied is transformed into a gross income or value productivity function through multiplying yield by price (a measure of value). The total cost function is the sum of fixed cost and the value of nitrogen applied (quantity times price). In this example, income is *good* and cost is *bad*. The right action is defined as applying that amount of nitrogen which maximizes the difference between *good* and *bad;* the decision rule is to maximize profit, since perfect knowledge is assumed. This simple example, illustrated in Figure 9, is based on simplifying assumptions, many of which are not met when public decision makers must deal with complex development problems involving technical, institutional, and human changes taking place under uncertainty. When the simplifying assumption of perfect knowledge is not met, the simple decision rule is not applicable.

Public decision makers are usually concerned with the attainment of multiple desirable consequences (goods) and the avoidance of multiple undesirable consequences (bads) under conditions of imperfect knowledge. Prescribing right actions under these circumstances becomes much more difficult and complex than in the simple example illustrated above. Four preconditions must be satisfied before a maximizing decision can be made [13, 74, 77]. A precondition for such a decision is agreement on an appropriate decision rule [42, 53, 57, 61, 64, 84, 175]. Much of the effort expended by the decision maker during the decision-making process is on determining the appropriate decision rule. Also, a normative common denominator, such as dollars or utility, must be available to permit the summation of the diverse *bads* and their subtraction from the summation of the diverse *goods*. Further, the normative common denominator must have interpersonal validity if *bads* imposed upon one person or group are to be subtracted from the *goods* conferred on another person or group [13].

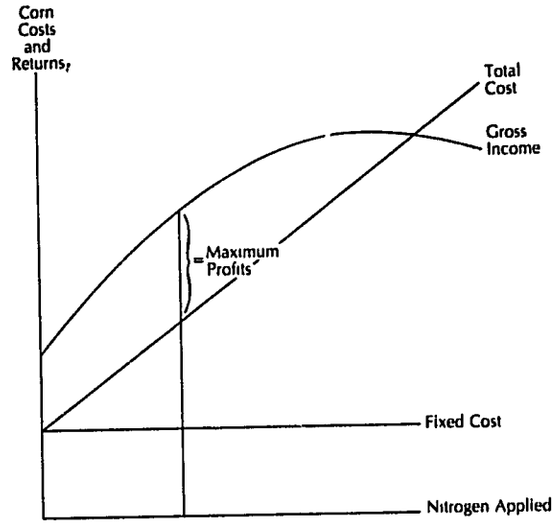

FIG. 9. Value productivity and input cost functions to determine the most profitable amounts of corn to produce and nitrogen to use.

Finally, either the order in which actions are implemented must be unimportant or the actions must be capable of being ranked in the order of their decreasing net advantage per unit of sacrificed *good* or incurred *bad*. In mathematical terminology, this is to say that the second-order conditions for existence of an optimum must be established. Many problem-solving research efforts involve great expenditures of time, effort, and money to establish the normative preconditions for maximization and the positive preconditions constraining action, while the actual maximization requires only a minor effort [85, 151].

Reaching a prescription generally involves some sort of maximization, although the maximizing decision rule may be much more complex than merely maximizing the difference between goodness and badness. With imperfect knowledge, decision makers follow various decision strategies, such as bringing the consequences of their actions to minimum acceptable levels, maximizing the average (expected) difference between *good* and *bad*, doing that for which the worst that could happen is better than the worst for any other possible action, bluffing, going to war, or flipping a coin [42]. In acquiring, analyzing, and synthesizing information and data to project the consequences of alternative courses of action, it is appropriate to use the resources available to the point where the marginal costs of

further iteration of the process would be greater than the marginal return in solving the problem [84]. The decision can be made on the basis of information and knowledge available at that point, the decision executed and the consequences of the action borne.

Perfect knowledge with respect to the four preconditions for problem solving decision is impossible. Normally, even to approach perfect knowledge would be prohibitively expensive. In the absence of perfect knowledge, power (market, political, police, and so forth) is embedded in various convenants as a necessary part of a decision rule [74]. Because the perfect knowledge required for concensus is infinitely expensive, the use of power eventually becomes cheaper than the investigation, analysis, and research necessary to produce new knowledge. Another optimum has to do with the distribution of power. Until a certain degree of power equality is established, feedback is thwarted by absolute control and possible repression. On the other hand, complete equality in the absence of perfect knowledge may lead to indecisiveness. Thus, optima exist with respect to both the certainty and stability of power distributions [74]. Uncertainty and instability lead to misunderstanding and/or conflict, whereas undue stability and concentration of power lead to neglect of problems and eventually to costly catastrophic change. Political, military, and socioeconomic institutions must be responsive and adaptable to changing realities to prevent the consequences of imbalances in power distributions.

Models in the Decision-Making Process

In spite of the uncertainty inherent in the process, decision makers responsible for social and economic development must make decisions (even no decision is a decision to do nothing); and in making those decisions, they must acquire information, data, and knowledge, imperfect as it may be, concerning the possible future consequences of alternative courses of action [74, 84]. In arriving at a decision for action (steps 4 and 5, Figure 8) the decision maker and his investigators must put the relevant data and information that have been collected (step 2, Figure 8) into a logical framework from which inferences can be drawn about the important consequences of alternative courses of action (step 3, Figure 8). This framework — no matter how simple or complex, informal or formal, impersonal or personal — can be regarded as a *problem-solving model*. In projecting the consequences of alternative courses of action, models are used extensively, since direct experimentation on the system is often uneconomic, dangerous, or physically impossible [127]. These models typically range from intuitive, mental images of the system through written or verbal descriptions to complex, computerized mathematical models [22]. Further, more than one type of model may be used to provide input for

any one decision. For example, a computerized mathematical model may be used to make projections of economic variables, whereas projections of political variables may be made with a mental model. A combination of such models is a necessary component in the total problem-solving model.

A model of whatever kind is an abstract representation of a system, socioeconomic or otherwise. It is abstract because it cannot deal with all aspects of reality [52, 94]. Given the intended purpose for which the model will be used, only characteristics of the system relevant to that purpose can be modeled; and even these characteristics will only be modeled to the level of detail sufficient for that purpose. Thus, assumptions and simplifications — what to put in the model, what to leave out, what to aggregate, how much to aggregate — are a necessary and inescapable part of modeling, whether a simple mental image or a complex computer program is being used.

The quality of a decision depends in large measure on the quality of the process undergone in arriving at that decision. The ability to acquire, assimilate, synthesize, and analyze data, information, and knowledge in an appropriate logical framework or a model will determine the quality of that process [21, 43, 44, 74, 84]. Thus, a necessary condition for enlightened public decision making is a broadly based and highly developed investigative capacity.

A GENERAL SYSTEM SIMULATION APPROACH

As governmental decision makers confront problems for which their mental and paper-and-pencil models are inadequate, they often turn to professionals from appropriate disciplines to build more complex models of reality, based on theoretical constructs and using mathematical representations of relationships to formalize the logical framework. Complex model building and mathematical representation became much more feasible with the introduction of large-scale electronic computers having the ability to perform extremely rapid calculations and to keep track of literally hundreds of variables and their interrelationships [85, 127, 151].

Mathematical models of economic subsystems of socioeconomic systems are being used in a variety of research, planning, and policy applications by both private industry and government, although mental and verbal models are still used heavily for analysis of political and social phenomena [71, 73, 74, 81]. Economic theory is useful, because it deals with quantifiable variables; and recorded data are sufficient for some work with the relevant structural and process relationships. Gaps in economic theory and data exist, however, particularly in the areas where economic and social phenomena are closely interrelated, such as in rural-urban migration and decisions of the farm unit as both a producing firm and a consuming

household. A formal logical framework or system model is needed which takes account of the structure, processes, and interrelationships of the total agricultural sector and its interactions with the rest of the economy and which is capable of addressing a broad set of problems related to agricultural sector development [85, 151]. The general system simulation approach incorporates such a logical framework.

The general system simulation approach to agricultural sector development decision making involves both the administrative and investigative sides of a country's decision-making capacity depicted in Figure 4 [38, 41, 85, 127, 151]. It facilitates and depends on strong and continuous interaction among administrators, investigators, and affected people, as participants in the decision-making process. It is eclectic with respect to philosophies, data and information sources and types, model types, the use and nonuse of various maximizing techniques, assumptions, and dimensions [77].

The approach gains its credibility in part from the joint participation of decision makers and investigators, and in part from its eclecticism, which is similar to that practiced by the decision maker himself [74, 77]. Although the approach is useful when applied only with informal mental models or paper-and-pencil analyses, the more formal the models used, the more comprehensive and specific the results. The core of the logical framework used in the approach is a model of the structure and processes constituting the system within which specific problems or problem sets are encountered and about which decisions must be made. When simple maximizing behavior is being predicted or prescribed, the appropriate decision rule can be incorporated in the formal model. When a more complex decision rule is indicated, it must be determined in interaction with, but outside of, the formal model [74, 77]. The approach is applicable to all types of research and modeling, but it is particularly applicable to the subject-matter and problem-solving types.

The example cited in this book focuses on a subject-matter model of an agricultural sector developed for national-level planning and policy decision making. The formal part of the model is computerized. It is composed of several components which can be run separately or in concert. With additional information and modeling, it, or its parts, can be modified and extended to focus on specific problems. Such a model must combine several characteristics not often found together in more limited models. *First*, it must be broad in its scope of analysis and general with respect to philosophies, techniques, and kinds and sources of data and information.

We have already discussed the broad philosophical orientation required for subject-matter and problem-solving research. It is sufficient at this point to reiterate the need for subject-matter and problem-solving

investigators, as well as decision makers, to draw from various philosophical positions, including normativism, positivism, and pragmatism, as appropriate.

The general system simulation approach makes use of a variety of techniques. Specific kinds of mathematical models using specific techniques have their own relative advantages and disadvantages. For example, programming models can determine the choice of actions that will optimize the attainment of a given objective, subject to constraints. Such models can be useful when the preconditions for maximization discussed above are met. On the micro level, such as a farm firm or other decision-making unit, such models can sometimes be used, since a single objective or combination of objectives may sometimes be reasonably assumed and interpersonal validity may be less of a problem. If a region rather than a single farm is being modeled, aggregation problems may be troublesome. On the macro level, where, for example, a sector or an economy is being modeled to optimize development objectives, preconditions are still harder to meet and aggregation problems become severe, thus making the use of programming techniques even more questionable than at micro levels [21].

Another specialized technique often used to perform policy simulations is econometric analysis with sets of simultaneous equations. The parameters of such systems are statistically estimated directly from observed and recorded time series or cross-sectional data on the performance of the system. These estimates are presumed to represent the parameters of the system being modeled. Unfortunately, time series and cross-sectional data, especially in developing countries, are often scarce, poor, or nonexistent; hence, a model based solely on such data may not represent the real-world system as adequately as models based on additional types and sources of data. In addition, statistical estimation procedures place severe restrictions on the form of mathematical equations in econometric models. Finally, a model that is based on historical data and that may be a fair representation of a system in the past will not necessarily be so in the future, particularly in planning development where technological, institutional, and human changes are the objects of the exercise [38, 76].

Other specialized techniques, such as input-output analysis, benefit-cost analysis, critical path analysis, and so forth, like programming models, are applicable only for particular purposes and only under special circumstances — where good data exist, where an objective function can be defined, or where a particular structural form (linear, quadratic, etc.) is justified. Although these models appear rather rigorous, they often lack credibility with decision makers because such models are very selective of the sources and types of data they will accept, as well as being unduly

specialized in other ways. Later we will discuss the close relationship between credibility with decision makers and the concepts of validation and verification. These models often fail to provide decision makers with answers concerning the wide array of consequences to be expected from a specific course of action, and they cannot easily be adapted to an assessment of the consequences of several alternative courses of action, particularly if simultaneous changes in several policies and programs are involved. Thus, credibility gaps develop between many governmental decision makers and their professional investigators with respect to the usefulness of these kinds of models.

In the general system simulation approach, any of the techniques discussed above along with various mathematical modeling and analysis and simulation techniques from systems science are employed, as appropriate and in various combinations, depending on the characteristics of the system being modeled and the requirements for decision-making information.

A specific technique used to model a specific process or behavioral characteristic is chosen because it is seen as being most appropriate for the job. Thus, techniques and knowledge are drawn from demographers, farm management researchers, public administration analysts, economists and econometricians, statisticians, engineers, systems scientists, operations researchers, and physical and biological scientists, as required, to improve the model until the value of the improvement in terms of usefulness to the decision maker no longer exceeds its costs in terms of money, timeliness, and skills required.

Kinds and sources of information and data used in the models vary according to availability and model requirements. They include time series and cross-sectional data, opinion and judgment of experienced professionals and practitioners, experimental and survey results, and "guesstimates." A major source of information, particularly of the normative type, is the decision maker himself; thus a great deal of interaction between the investigators and the decision makers is required.

Second, the model must be capable of tracing the consequences of specific decisions and policies across a wide variety of dimensions of interest to decision makers. Since human, institutional, and technical change through time is of major importance, primary emphasis is on the time dimension. Other dimensions of likely importance include space, demographic characteristic, economic function, commodity category, input category, and so forth.

Third, the subject matter dealt with by the model must be viewed as a system comprised of subsystems and itself as a subsystem of a larger system. A building block concept is employed in which relatively self-

contained economic, technical, or biological functions or processes take place within specified model components [123]. As specific problems are identified, the appropriate building blocks or model components can be chosen and linked in the proper configuration to provide analytical input to specific solutions to a problem.

Combining the computer with the methodology and orientation of the general system simulation approach and with the conceptualization of problems within a sector framework provides a formal, computerized, general system simulation model of an agricultural sector with the capacity to address a broad set of problems of concern in agricultural sector development. Such a model can be a valuable analytical tool in helping decision makers in their planning, policy formulation, and program development activities. Further, such a model can be of use for a virtually indefinite time period, with periodic updating and modification to continue to accurately reflect the system under consideration.

Because it is designed to provide input to a set of problems concerning agricultural sector development, it is a subject-matter model [74]. It is both broad enough and detailed enough, however, that in most cases relatively minor modifications and extensions allow all or parts of it to be used in specific applications to solutions of specific problems in the problem set for which it is designed. It is used in an iterative and interactive context by investigators and decision makers in carrying out the functions of the decision-making process.

Conceptually a formal system simulation model of an agricultural sector focused on planning and policy analysis can be viewed in the following general mathematical form [127, 151]:

$$\psi(t + 1) = F[\psi(t), \alpha(t), \beta(t), \gamma(t)]$$
$$\pi(t) = G[\psi(t), \alpha(t), \beta(t), \gamma(t)]$$

where

$\psi(t)$ = a set of variables defining the state of the simulated system at any given time. State variables may include such quantities as production capacities, prices, population by subgroups, levels of technology, etc.

$\pi(t)$ = a set of output variables indicating system performance, such as profit, income, growth rates, balance of trade, employment, nutrition, etc.

$\alpha(t)$ = a set of parameters defining the structure of the system. These parameters usually regulate rates of change between levels, through time, or through space, such as input-output coefficients, technical coefficients, behavioral response parameters (these may or may not presume maximization), price and income elasticities, migration rates, birth and death rates, etc.

$\beta(t)$ = a set of environment variables, such as world prices, weather, etc.

$\gamma(t)$ = a set of policy instruments, such as price controls, tax policies, production campaigns, investment alternatives, etc.

The state equation (ψ) is a general representation of the difference equation formulation of the system model describing the state of the system at discrete points in time. The output equation generates the variables (π) necessary in the model application stage to evaluate, in terms of the goals specified in the problem definition, the performance of the system over time under various policy alternatives. Both normative and positive knowledge are incorporated into the model [77]. In some cases, where simple maximizing behavior is observed, such behavior is easily modeled. In other instances a model can be run in an optimizing mode to find optimal policies, programs, or project organizations. When a formal model is not run in an optimizing mode, informal interactions with decision makers and/or affected people are required. When modeling behavior or finding optima, maximization involves the use of decision rules and associated political and socioeconomic covenants. The result is in effect a mixed man/computer model.

The formal computerized model is realized in the hundreds or even thousands of parameters and structural and behavioral relationships incorporated in the model. Actual specification of the model requires (1) precise description of the model components; (2) explicit algebraic, difference, and/or differential equations to represent the structures, processes, and mechanisms within components and the linkages between components; and (3) programming for computer implementation.

Such a model consists essentially of three parts. The first is the logical framework, which attempts to reflect the structure and processes of the real world [25, 29, 93, 130]. This logical framework is explicit in the model in various forms, ranging from a verbal description facilitated by block diagrams, through a set of mathematical equations, to a list of FORTRAN subroutines and statements that spell out the equations and linkages in an operational, computerized model. In general this is the model structure. The more comprehensive and complex the model representing the complexity of the real-world system, the greater is the detail and complexity of the model structure.

The second part of the model is the estimates of the parameters or the coefficients indicating the quantified values of the linkages in the model [25, 31, 87, 93, 130]. The coefficients are determined, found, or estimated for the most part outside the system's model structure. Any and all of the traditional parameter-estimating techniques are used, as appropriate.

None are precluded — none are required. Data and information are brought to bear from whatever sources are available and relevant.

The third part of the model is the data reflecting the initial conditions for the base period from which the model begins its simulation. Although interrelated, these three parts may be viewed, worked on, and improved separately. Thus, model structure can be changed to reflect more accurately the real-world system without improvement in the estimated coefficients or the initial-condition data. Similarly, more accurate, more reliable estimates of parameters can be incorporated into the model without changing the structure or the base-period data. And finally, base-period data can be updated or changed for greater accuracy without changing either parameter estimates or structure. For broad-gauged model development, improvement, and application, work on all three fronts must be continuous. If the model is not run in an optimizing mode, a fourth part of the model (or necessary addition to it) is the decision maker and affected people with whom the investigators must interact when the model is used for problem solving.

Figure 10 depicts both the formal and informal modeling components. The formal modeling process has three phases: the problem-definition phase (roughly analogous to steps 1 and 2 of the decision-making process depicted in Figure 8), the system simulation phase (roughly analogous to steps 2, 3, and 4 of Figure 8), and the policy formulation and implementation phase (roughly analogous to steps 4, 5, and 6 of Figure 8). The informal interaction discussed above appears at the top of Figure 10.

As with the decision-making process, normative and positive information is required [93, 119, 135]. The consequences of deficient information can be determined through such techniques as consistency checks, sensitivity analysis, and tracking experiments and new information can be sought, if judged to be worthwhile. The whole process is highly iterative, and decisions are a result of the interactions between the information, modelers, analysts, and the decision makers themselves.

The problem-definition phase entails the explicit and precise identification of values ("goods" and "bads" or system performance criteria), relevant alternative policy instruments, and system and policy constraints [74]. An optimizing analysis may indicate the level at which the nation should expect its agriculture to feed itself and the rest of the nation and to support nonagricultural growth by supplying resources and demanding nonagricultural goods and services. Values may specify that increasing income is good, but that inequitable distribution of income between agriculture and nonagriculture and within each of them is bad; that agriculture supplying labor to nonagriculture is good, but that urban unemployment is bad, and so on. Given the values, alternative policies might be

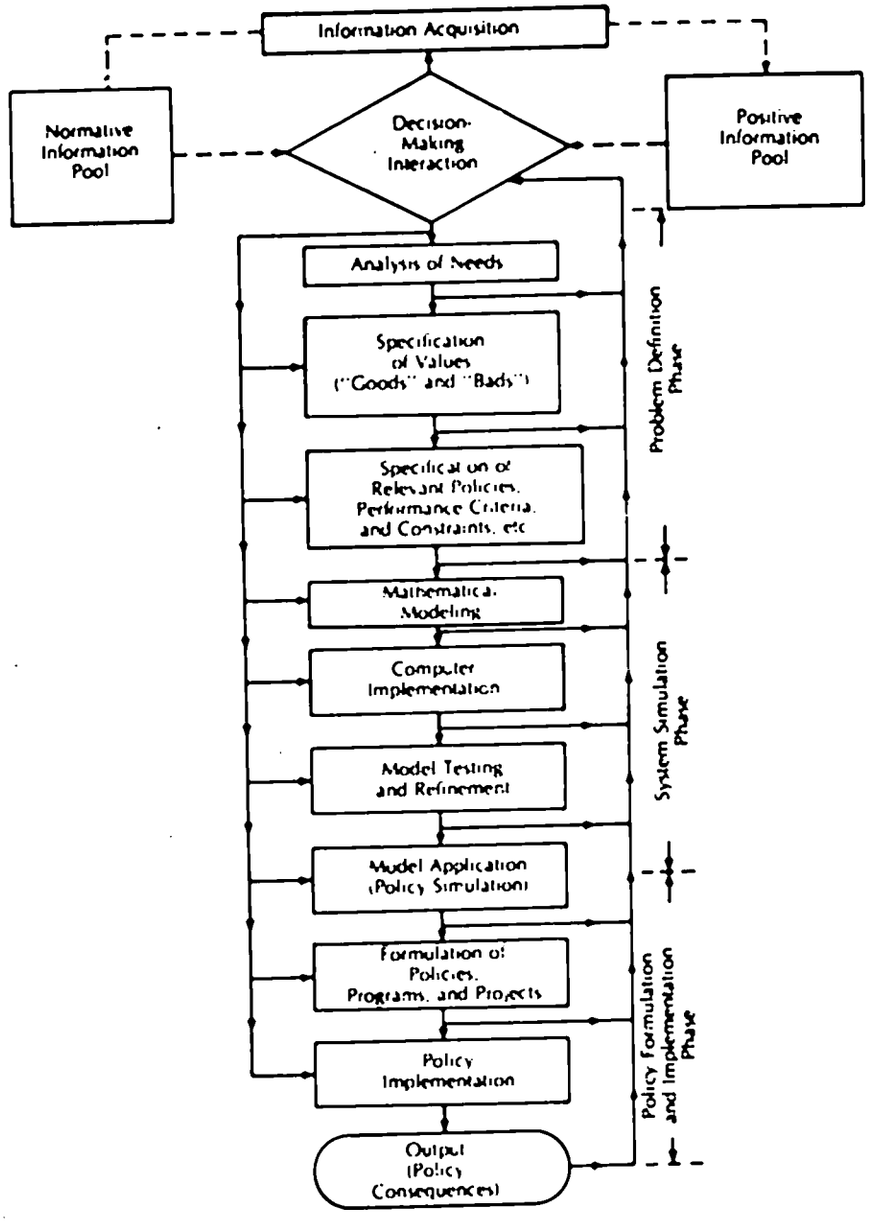

FIG. 10. System simulation and the decision-making process.

devised to increase the productivity of agricultural resources, to improve the efficiency of the marketing and distribution system, and/or to promote import substitution and export production in both agriculture and nonagriculture, and so forth [137].

Alternative instruments for carrying out such policies might include the use of tax rates as incentives and as sources of revenue to finance other programs and projects, production campaigns to increase the efficiency of agricultural resources, irrigation and mechanization programs, producer pricing policies, or setting foreign exchange rates and import quotas. Relevant performance criterion variables might include levels and growth rates of GNP, per capita income, calorie and protein consumption, trade balances, or unemployment.

People in development planning and policy analysis will find nothing new in this. Its formalization is necessary, however, to determine what sort of model to build; that is, what subsystems and components should be identified and the level of aggregation desired of each, what policy instruments should be included, what performance criteria should be generated (π in the above equations), etc. The model is then built and programmed for implementation on the computer.

The most important reason for developing a simulation model (in this context) is to provide a low-cost means of exploring the consequences of a wide range of alternative plans, policies, or management strategies. One simulation experiment can lead to the development of a new and better design, which may involve reprogramming or even basic modifications of the model. The objective of such simulation experiments is to unfold a set of development strategies that are consistent and mutually reinforcing and to show how resources could be effectively used to solve the basic problem (as defined).

Policy simulation results may suggest further alternatives to be tested in an iterative process of policy formulation. Eventually, a decision is made to implement a particular set of policies [42]. Most often the decision is based on interaction between investigators and decision makers, rather than solely on a formal model operating in a maximizing mode [12, 74]. The real-world consequences of that decision will influence later policy formulations and may even lead to a redefinition of the problem, thus continuing the iterative decision-making process, with further modeling integrated as part of the process [54, 55, 154].

Credibility

A prerequisite for use of any model for problem-solving purposes is its acceptance by decision makers [74]. Model builders and disciplinarians often expect to achieve credibility and acceptance by decision makers

through simple validation and verification of their highly specialized models. This is not sufficient to gain credibility with decision makers, as has been painfully proven over and over again for specialized models built by investigators using specialized techniques and data [38, 77]. Even though such models pass the usual validation and verification tests, they are often rejected by decision makers as irrelevant, too complicated, too narrow, or just plain wrong. In a broader, very legitimate sense, they are neither validated nor verified.

The concepts of validation and verification have had a wide variety of meanings among scientists and decision makers [25, 29, 52, 70, 135, 152, 153]. Usually validation has meant testing a concept, theory, or model for internal logical consistency [29]. Verification generally means testing a concept or model with respect to its ability to reflect accurately the real-world situation or phenomenon it is intended to represent through its capacity to track historical data and to project accurately the behavior of important variables of a system into the future [29, 87]. Validation is a test of coherence, whereas verification is a test of correspondence.

Models and the concepts and theories used to build them must also pass the test of clarity in order to achieve credibility with decision makers. That is, the model's concepts and theories must be explainable and understandable to those who use them if they are to be accepted; scientifically, they must be clear and unambiguous *before* the tests of coherence and correspondence can be applied. Finally, they must pass the test of workability when used to solve problems [140, 153]. The workability test evaluates the prescriptions based on the model in terms of how well they perform in the real world, judged by the good results achieved and bad consequences avoided. Simply stated, the workability test requires that models help *solve problems* of real-world decision makers, not just answer positive and normative *questions* of disciplinarians or other curious people. Thus workability is a test of the model's prescriptive ability [74, 121, 124]. The utility of a model increases with success in passing and decreases with failure to pass these tests.

A specialized model can pass the validation (coherence) test in the narrow sense but still fail it in the broader sense in which a decision maker views the situation because of the omission of logic required to model the entire domain of the problem. This happens, for instance, when an economist omits essential technical or institutional concepts known by decision makers to be important. A model can also pass the verification (correspondence) test in the narrow sense but fail it in the broader sense if it does not consider or project variables known by decision makers to be relevant. It also fails the test of clarity if it is not clear enough to be understandable and explainable to the decision maker. Finally, it may fail

the workability test if the prescriptions derived from it are known by the decision maker to be inappropriate or insufficient.

It should be clear that establishing credibility is not a one-time procedure, but rather an iterative process that goes hand in hand with adapting and using models in a variety of problem-solving applications [74, 84, 140, 153]. Feedback from use increases credibility and credibility increases use. The tests of coherence, correspondence, clarity, and workability need to be applied repeatedly in the development, institutionalization, and use of models. Intensive and continuous interaction among model builders, analysts, and decision makers plays a key role in performing these tests.

In the final analysis, as the saying goes, "The proof of the pudding is in the eating." If the models are used over time by decision makers in solving problems and if those solutions attain more of the "goods" and avoid more of the "bads" than was possible with alternative model constructs, they pass at least the minimal standards of the four tests of credibility.

The general system simulation approach, because it is eclectic with respect to philosophies, data and information sources and types, and the use, nonuse, and delayed use of maximization, modeling techniques, and dimensions; and because it can be used with relative ease to project the likely consequences of alternative policies, can be made an integral part of the decision-making process. Its eclecticism approaches the institutional eclecticism of decision makers, thus facilitating their participation in application of the approach. With decision makers' participation throughout the process, including the application of the tests of coherence, correspondence, clarity, and workability, the formal models can become institutionalized directly into the decision structure as part of the investigative capacity. Hence, the credibility gap often observed among decision makers, professional analysts, and modelers is greatly diminished.

3
Values and policy choices in agricultural development

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INTRODUCTION

Normative knowledge concerning broad national values providing the philosophical environment and orientation for agricultural sector development must be sought by investigators and decision makers. The agricultural sector operates within and interacts with an environment composed of other sectors of the national economy. In this chapter we begin with a discussion of the relationships between the agricultural sector and the rest of the economy. We then turn to a discussion of the relationship between the values important in development of the agricultural sector as an integral part of the national economy and the range of policy choices available to the decision maker to promote that development.[1]

AGRICULTURE AND THE NATIONAL ECONOMY

In most developing countries, agriculture is the largest single sector of the economy, both in terms of population employed and of contributions to gross domestic product. In some countries subsistence farming is the predominant way of life in the national economy, and the interactions between the agricultural sector and the nonagricultural economy are almost nonexistent. As urban and industrial sectors develop, however, and as migration from the farm to nonfarm sectors occurs, commercialization of agriculture and linkages between agriculture and other sectors of the economy begin to take shape.

Development of the nonagricultural sectors of an economy implies an increase in the relative proportion of nonagricultural population. Farm-to-nonfarm migration, natural population growth in the nonfarm sector, and increasing per capita incomes are factors requiring commercialization of agriculture. Increases are also required in the capacity of the marketing, processing, storage, and transportation systems to handle increased volumes of agricultural commodities flowing from the farm to the urban areas. Shifts occurring at the farm level in response to these demands include pressures to increase agricultural production and, because of a move from subsistence to commercialization and higher nonfarm incomes, a rapid adjustment in the proportions of crops and livestock produced.

The interactions between agriculture and the rest of the economy have the potential for becoming large and complex as development occurs. The following list discusses the most important of these interactions.

Food

By far the major contribution of any agricultural sector to the rest of its national economy is the provision of food commodities. The demand for food in the aggregate is derived from two sources — population growth and per capita income levels. The effect of population growth on the demand for food is obvious. The effects on food demand of changing demographic characteristics within the population, such as age structure, labor force participation, or location of residence, require more detailed analysis. The effect of per capita income on food demand has both quantitative and qualitative aspects. As per capita incomes rise from extremely low levels, the major effect is an increase in the demand for more of the same kinds of agricultural commodities to satisfy a higher level of per capita consumption. As incomes increase further, a shift to preferred kinds of food commodities predominates. This shift is predictably from the staple food grains toward meat and dairy products, fruits, and vegetables.

Labor Supply for the Nonfarm Sectors

In developing economies, off-farm migration and off-farm employment by members of farm households are normal phenomena. These movements can be regarded as a major contribution of the agricultural sector toward the development of the nonfarm sectors. Over time, these movements cause both a relative and an absolute decline in the portion of population engaged in agriculture, which implies that investments in rural education, vocational training, health, and sanitation are important for the rural economy and, as off-farm migration increases, they become increasingly beneficial to the nonfarm sectors.

To assure that national interests are well served, while at the same time considering individual welfare, government policies and programs in agriculture and elsewhere should be attuned to influencing migration rates to keep them in line with the absorptive capacity for such labor in the nonfarm sectors. Migrants should not find themselves in a position of trading underemployment and low incomes in agriculture for unemployment and slum dwelling in urban areas. Both the overall rate of migration and the composition of the migrant stream by age, sex, and skill levels are important in assuring an orderly and rapid transition into available jobs in a developing nonfarm economy. Urban areas should not be required to suffer from having to provide services for jobless migrants, nor should rural areas suffer from loss of labor and transfer of rural wealth with migrants.

Raw Materials for an Expanding Industry

In many developing countries, a significant portion of the agricultural activity provides nonfood raw materials for domestic processing and use or export. Examples include fibers, such as cotton, wool, wood, hemp, sisal, copra, and silkworm cocoons; livestock by-products, such as hides and pig bristles; rubber; oils; and grains and other commodities for industrial production of alcohol and starches. In the early stages of economic development, most countries producing these types of products export them as raw materials. As the industrial base becomes established, opportunities arise for processing industries to supply both domestic and export markets with more highly processed forms of these basic raw materials.

Export Earnings and Foreign Exchange Savings

The agricultural sector in most developing economies can be an important source of foreign exchange, whether through exportation of domestically produced agricultural commodities and agriculturally based processed goods or through increased production of agricultural commodities for domestic use to substitute for imports. Governmental policies and programs to provide proper investments and incentives to direct agricultural production towards these objectives are required in most cases. Constant reassessment by government is necessary to ensure that the efficiency of resource allocation, in accordance with comparative-advantage principles, is maintained to the greatest possible extent, given the need to satisfy domestic welfare objectives and equity criteria.

Capital Generation for Increased Rural and Urban Productivity

The agricultural sector is probably a greater source of capital for development of the farm and nonfarm economies than is commonly

realized by governments or in lender and grantor circles because of the overlooked processes of (1) income transfer associated with migration and (2) the formation or production of specialized capital in agriculture by the person who "saves" and invests without using the services of money markets. Nonagricultural development can be financed in part by capital surpluses forcibly extracted from agriculture through taxation, unfavorable terms of exchange from state trading organizations, or through investments by wealthy rural families. Even when none of these is occurring, income and capital transfers from farm to city take place. For example, migrants leaving the agricultural sector will usually take with them an inheritance claim on agricultural stock. In addition they may receive rents or payments based on the agricultural production from these claims on an annual basis. They also are likely to receive gifts of food from their rural relatives. Offsetting this outflow are the reverse flows of income from the migrants to the rural areas in the forms of gifts and grants to the families left behind. In any event the net flow is likely to be from the farm to the urban sectors.

Government activity should also be taken into account in any determination of capital and income flows between agriculture and the rest of the economy. The net flow of taxes, government revenues, expenditures, subsidies, and other transfers between rural and urban sectors can be calculated, provided the data are available.

None of these calculations will include the nonmonetized contributions from agriculture to the nonfarm economy, including the value of human capital in off-farm migrants and the fact that labor and much of the capital used in the production of agricultural commodities for the nonfarm economy is very poorly paid. The agricultural sector traditionally has generated much of its own capital. Buildings, cultivated trees, livestock, and farm-produced equipment are but a few examples.

Land for Nonagricultural Use

With increased urbanization and industrialization, the demand for land for nonagricultural uses increases. Land is needed for new urban and suburban housing, industrial and commercial sites, streets, parks, reservoirs, and urban service areas. In addition, an increasing amount of land is used for roads and utilities. In land-scarce economies this means that agricultural productivity must increase and/or high-cost land reclamation must be financed to replace converted land to maintain a given production level.

Quality of Life

A prosperous, productive, socially and politically stable agricultural sector, properly served by a well-functioning infrastructure, is an important

asset for any nation. Not only is such an agricultural sector essential in providing for the nonfarm demands indicated above, but also in providing a favorable environment for work, leisure, living, and learning by farm people.

Agriculture as a Consumer of Nonfarm-Produced Goods and Services

In the category of demands placed upon the agricultural sector, not all goods, services, and human flows are from the farm to nonfarm destinations. As the balance of population tips away from the agricultural sector and/or agricultural exports gain in importance, the subsistence mode of agriculture gives way, through a commercialization process, to market-oriented agricultural production. With this commercialization comes an increasing demand by agriculture for nonfarm-produced modern inputs, such as tools, machinery, chemicals, and commercial fertilizers, as well as nonfarm-generated capital and credit. Also, the increased cash incomes derived from the commercialization of agriculture allow farm household members to increase their effective demand for consumer goods and services produced in the nonfarm economy. This market link between agriculture and the rest of the economy creates opportunities for industrialization, commercialization, and the use of nonfarm capital and labor to satisfy the agricultural sector demand, thus further increasing the growth potential of the overall economy.

DEVELOPMENTAL RELATIONSHIPS AMONG VALUES AND POLICY CHOICES IN AGRICULTURAL SECTOR DEVELOPMENT

To ensure an orderly and productive process of development and the satisfaction of the nonagricultural demands placed on the agricultural sector with a minimum of hardships on the individuals concerned, government must play a major role. To carry out this role effectively through planning and policy decision making requires a body of normative and positive knowledge and concepts from which decision makers can draw in making problem-solving prescriptions. We deal with the acquisition and use of positive knowledge in subsequent chapters. The process of building a stock of normative knowledge and developing an awareness of its implications must be carried out through interaction among decision makers, analysts, and those who are affected by the decisions. Illustrative groupings of values and relationships among values representing this normative knowledge useful in determining appropriate policy choices for development of an agricultural sector in a developing country are examined in the remainder of this chapter.

Values, or concepts of goodness or badness of a condition, situation, or thing, can be viewed as either instrumental or basic. Instrumental values

are concepts of goodness or badness derived from more basic values. For example, the concept "it is good for man to have money" may be based on the more basic value concept "it is good for a man to be able to provide food and shelter for his family." Basic values contrast with instrumental values in that they are *goods* for the sake of which instrumental values are actualized. Basic values may ordinarily be actualized by a number of different instrumental values. In the above example, providing food and shelter for a man's family might be realized by means other than having money, such as through self-sufficiency or theft. Thus, it should be remembered that an instrumental value detached from the more basic value with which it is connected may very well be bad. For example, costs associated with agricultural production may be viewed as bad but may be recognized as necessary in order to attain a profit viewed as good. It should be recognized also in the example above that still more basic values, such as that of life itself, may make the values of food and shelter, which are more basic than money, into instrumental values.

The definition of instrumental and basic values takes into account those vertical relationships among values encountered when considering the value of a resource that is a means of attaining a more basic value. For example, fertilizer has value because it is a means of producing food grain, which has the more basic value of providing human nutrition. Similarly, vocational training has value because it is a means of increasing the production of more basic goods and services. At other times the relationships among values are horizontal, having to do with two or more values on essentially the same plane, such as the values of rice and barley, both of which provide human nutrition, but neither of which is a means of attaining the other.

In many circumstances means that have instrumental value can be used to attain several different, more basic values. In some circumstances the means available to society are relatively fixed. If such means are useful in attaining one of two or more basic values, their value is determined by what the economist calls the principle of *opportunity cost;* that is, the cost of using the means to attain a more basic value is the sacrificed attainment of the other values, which could have been secured with the same means.

In other circumstances a means that has instrumental value may be used to attain two or more different basic values simultaneously. In this case the more basic values attained can be viewed as joint products of the means. In still other cases use of the means to attain one or more basic values must be reconciled and conflicts resolved by choice of one or another of the values.

It must be pointed out that we are considering both monetary and nonmonetary values, and thus opportunity costs are nonmonetary as well

as monetary. In the discussion of values to be presented in the remainder of this chapter, many references will be made to both nonmonetary and monetary opportunity costs in considering alternative uses for scarce means.

Decision makers have before them at any given time a number of values among which they can choose — both the basic values to be achieved and the means to obtain those basic values. Their choices among these values are crucial in setting the goals and targets to be attained in developing an agricultural sector within the context of a growing total economy. Government attains values through plans and policies designed to achieve specific goals. A plan or policy strategy set can be formulated with mutually supportive programs and projects designed to achieve a set of goals which, if properly specified, will maximize the difference between *goods* and *bads* involved within and among the basic and instrumental values of importance.

We will examine four possible values sets (combinations of instrumental and more basic values) that appear likely to be important for agricultural sector development in any developing country. These are the value sets associated with (1) quantitatively and qualitatively improved food supplies, (2) realization of a higher quality of life in rural areas, (3) contributions from the agricultural sector to national economic development, and (4) administrative and political processes affecting the agricultural sector. Though values such as these are not likely to be explicitly stated by policy makers or policy documents, a review of a country's policies, programs, and projects and interactions with policy makers will undoubtedly lead to identification of value sets similar to those stated as partial determinants, along with the necessary positive knowledge and prescriptive analysis, of the directions in which the agricultural sector should be developed.

Although the concepts in the following discussions generally apply to a wide range of agricultural sectors in developing countries, they derive from the collection and assimilation of normative information associated with the Michigan State University project in Korea. Thus, to the extent that the discussion is biased in any direction, it will tend to focus on a food-deficit country with scarce foreign exchange; limited agricultural resources, particularly land; a relatively well-developed and growing nonfarm economy; and a moderate rate of population growth. The reader can easily adapt the arguments to countries with differing characteristics.

Improved Food Supplies

In considering the value set concerned with improving food supplies, attention must be given to the value of a nation's food-producing resources and the costs of supplementing or diverting those resources, importing or

exporting food, and changing food consumption. In a food-deficit country, two means are possible over time to balance food production with consumption. Figure 11 reveals how these two means are related to values, constraints, and other means of obtaining values in the food supply set. (In the text which follows, numbers in bold face type refer to the numbered boxes in Figures 11, 12, and 13.)

One means of improving the food balance is through policies designed to decrease the rate of increase in food demand. This can be achieved through reduction in the rate of population growth(**1**). Population growth rates can be affected by population control (**2**) and through out-migration (**3**). Investments in family planning programs (**4**) can provide information (**7**) and devices (**6**). If a given percentage rate of growth is achievable with present investments in population control programs, an important question to ask is, What would lower this rate to an even more desirable target? Are there other means, such as economic incentives or penalties (**5**), that would contribute to a lower rate at a lower cost? Housing-size policies, a progressive educational head tax, or a regressive income tax deduction for larger families might be considered among these policy options.

Another means of obtaining a more favorable balance between population and food supply is to increase the supply of food (**8**), which can be done through increasing domestic food production (**9**), through importing food products (**10**), and through increasing marketing efficiency (**11**). Even with effective population control, most countries would probably need all these means to increase per capita food supply.

Imports, although they contribute to the improvement of the population-food balance, have some potentially unfavorable consequences. One direct effect is that they drain scarce and valuable foreign exchange; they may also depress domestic farm prices and incomes by competing with domestic production. Both of these "bads" may be offset through reallocation of released domestic resources from import-substitution agricultural production to export production (agricultural or industrial), or to industrial import-substitution production, and through import policies designed to manage domestic prices at acceptable levels.

Domestic agricultural production (**9**) can be increased through increasing yields (**12**) on the existing land and livestock base or through increasing the land area (**13**) allocated to agriculture for the support of either food crop production or livestock. Increasing yields can be attained with new or existing technologies (**14-19**). Improved cultural and animal care practices through new methods, techniques, and better management can improve yields at a relatively low cost. Selective breeding, development of new seed varieties, application of crop protection chemicals, use of proper amounts and kinds of fertilizer, and development of new irrigation and

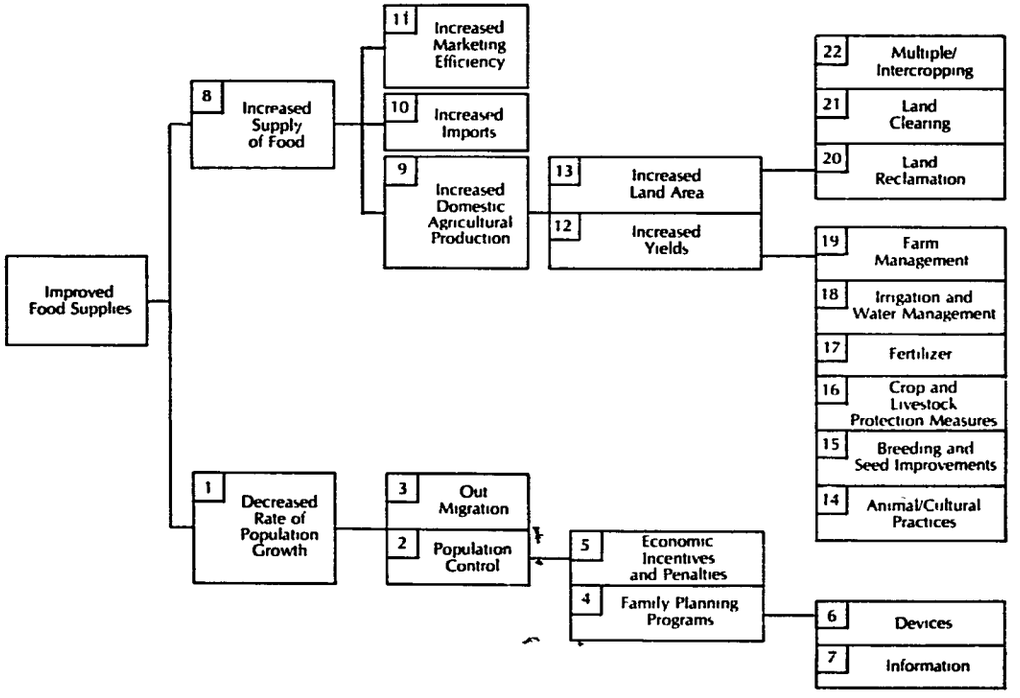


FIG. 11. Values and constraints associated with improved food supplies.

water management all can contribute to increased yields per unit of land area. In many cases these technologies are complementary and must be introduced as a package if they are to have value in increasing yields beyond those attainable when one or more components is missing. A broadly based, aggressive, and continuing agricultural research program, along with an effective delivery system to disseminate the information and research results to farmers, has substantial instrumental value.

The land area available for agricultural production can be increased through reclamation and land-clearing programs (**20-21**). Land reclamation for agricultural purposes often can be justified only as part of more general multipurpose river or rural development projects. Another means of increasing effective land area is through extension of the techniques of multiple cropping and intercropping (**22**). In all of the above investment choices and priorities an overriding concern must be to assess the values and trade-offs in using governmental and private investments for agricultural purposes as opposed to other public needs.

Improved Rural Life

Emphasis in the economic development of the agricultural sector in a developing country may be focused on agricultural production in the early stages, but at some point the emphasis turns to the quality of rural life. Figure 12 indicates the choices to be made in the value set contributing to improved quality of rural life. These choices include higher agricultural incomes (**23**), control of income distributions (**51**) — both between agriculture and other sectors of the economy and within agriculture itself — expansion of rural infrastructure (**54**), and preservation of personal freedom (**67**). Since agriculture normally represents a major portion of the population and activity of the rural sector, increasing per capita agricultural incomes (**23**) is a direct means of upgrading the quality of rural life. Per capita incomes can be increased in turn by increasing the value of agricultural production (**24**), thus providing more income to share among a given number of farmers. A decrease in the number of farmers (**39**) also would increase per capita incomes of those remaining. Decreasing costs per unit of output (**36**), while maintaining prices, is a third means.

The value of agricultural production can be increased both by increasing agricultural prices (**25**) and by increasing the volume of production (**26**). Prices can be increased by increasing relative demand (**27**), decreasing relative supply (**29**), or increasing market efficiency (**28**). Demand is increased through increases in population (**30**) (more mouths to feed), increases in per capita income (**31**) (people eat more and more highly valued food), and increased exports (**32**). If the net effect of these factors is

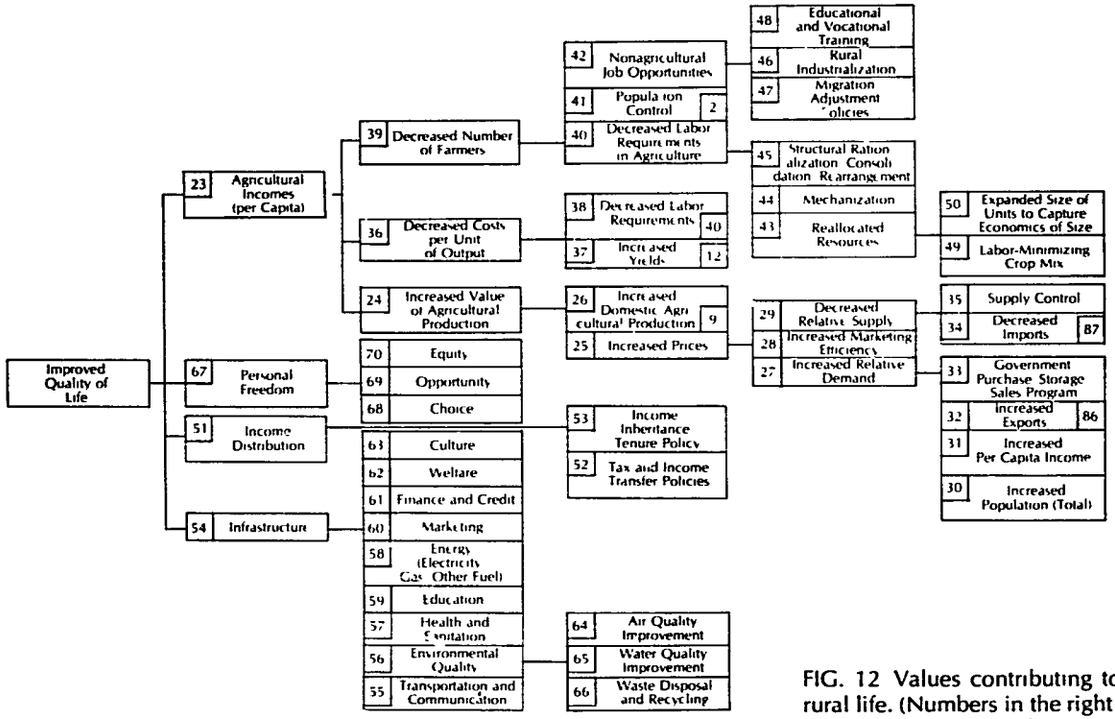


FIG. 12 Values contributing to the quality of rural life. (Numbers in the right corners refer to thoses boxes in either figure 11 or 13 and indicate linkages necessary to complete the line of reasoning.)

great enough to increase demand faster than supply, relative demand increases and puts upward pressure on prices.

Another means of increasing demand at least slightly and making it more uniform over time is through the operation of various government programs (**33**). Such programs might include mechanisms such as price supports and buffer stock operations designed to stabilize prices over the crop year.

In a food-deficit country, relative supply(**29**) can be affected by agricultural import policies. A decrease in imports (**34**) will decrease relative supply and increase domestic prices. Another possible valuable effect is to decrease the direct foreign exchange requirements. But other consequences of this kind of policy include effects on consumer prices, nutrition, and domestic resource allocation.

Other control measures on supply (**35**) can be taken between commodities through pricing subsidies, licensing, or contracts to shift resources to produce the desired output mix. Analysis is necessary to determine consequences of specific policy actions. In any case, one of the most effective means of increasing prices from the supply side in a food-deficit country is through restraints on imports, with selective supplemental measures on individual commodities.

Measures to increase marketing efficiency (**28**) also can have the effects of increasing producer prices, to the extent that market savings are passed on to producers, and of lowering food prices to consumers, to the extent that savings are passed on to consumers. Adequate facilities for bringing buyers, sellers, and products together; facilities for storage, transportation, and communication; and processing facilities are necessary to improve market efficiency.

Another means of increasing the value of agricultural production is to increase output, as measured by domestic agricultural product (**26**). Measures to accomplish this are indicated under (**9**) in Figure 11. Increased agricultural production must receive major consideration because it contributes to attainment of values concerning food, quality of life, and general economic development.

Per capita agricultural incomes can also be increased by decreasing the number of farmers (**38**). For this to be accomplished, the agricultural sector must be restructured in such a way that fewer farmers are needed in total and that seasonal peaks in labor requirements are minimized (**40**). In addition, the farmers who are willing and able to leave agriculture must have alternative employment opportunities in the nonfarm economy (**42**). A force somewhat less significant in contributing to a decline in the number of farmers is general population control (**41**).

Labor requirements in agriculture can be reduced in several ways,

including mechanization (**44**), rearranging and consolidating land (**45**), reallocating resources (**43**) to produce a labor-minimizing crop mix (**49**), and reducing the number and increasing the size of individual farms to make more efficient use of existing labor and other resources (**50**). Pressures for these kinds of adjustments will build as the labor supply becomes less plentiful in rural areas and as agricultural labor wage rates rise. Some adjustments to a shortage of labor may cost relatively little. Others, such as full-scale mechanization programs, may require considerable cash outlays from farmers. As labor flows out of agriculture and as agriculture becomes more commercialized in input and output markets, capital requirements will multiply and credit needs will become acute. Delivery of adequate and timely credit at reasonable cost to the agricultural sector is a major challenge in most developing countries.

A number of means of providing nonagricultural job opportunities for those people who leave agriculture (**42**) will be necessary. In order to pull enough labor from rural areas to man a growing urban industrial complex, migration adjustment policies (**46**), possibly in the form of migration and resettlement allowances, may be used. If the rate of off-farm migration is higher than the absorption capacity of the urban industrial complex for labor, these programs would have a negative value. Urban areas may suffer from having to provide services for jobless migrants, and rural areas may suffer from loss of labor and transfer of rural wealth with those same migrants. A population dispersion policy that includes rural industrialization (**47**) would slow the rural-to-urban migration rate. In any case, as the total economy develops, the basic age level for compulsory education is likely to increase and additional vocational training and retraining investments (**59**) will usually be required to provide the industrial labor market with laborers who have the necessary skills and education. These skills are most appropriately provided in rural areas, and governments should be willing to use investment transfers to upgrade the rural educational resources.

The third method of increasing per capita agricultural income is to decrease the cost per unit of output (**35**), thus increasing the net return with a given set of product prices. This can be accomplished by increasing the yields per unit of land area (**37**) and/or per unit of labor input (**38**). Both land-saving and labor-saving technologies can contribute to this objective. Labor-saving devices can greatly increase the quality of rural life by reducing the drudgery and the amount of hard, slow-paced labor required, but not if their use creates unemployment.

Another means of improving the quality of rural life is to influence the distribution of income (**51**) toward increased equity, both within the agricultural sector and between the agricultural and nonagricultural sectors.

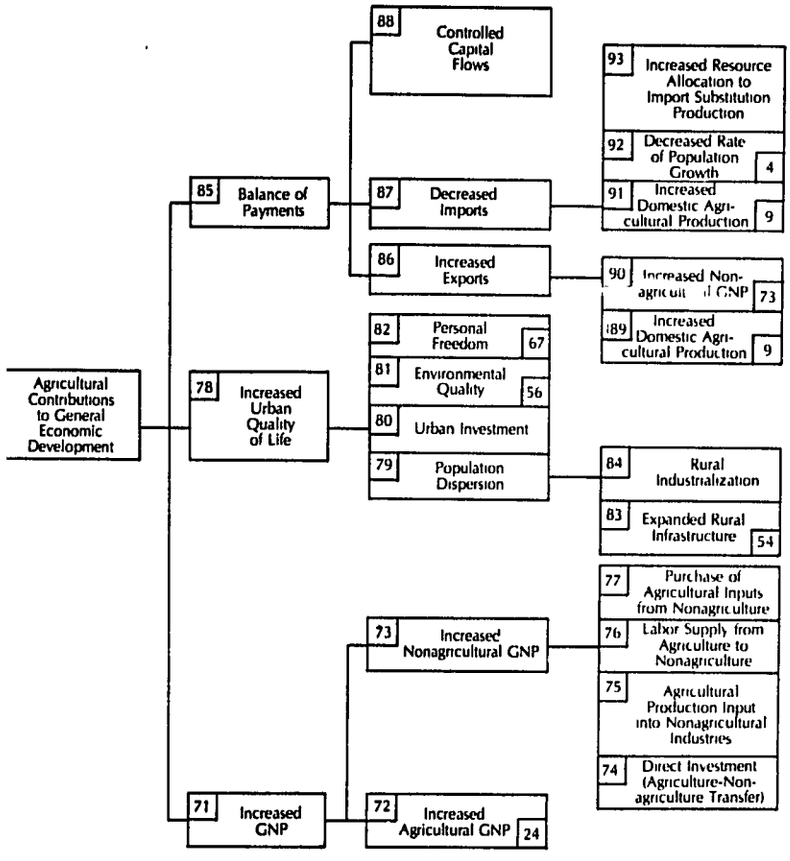
It should be noted that many policies, particularly price and income policies, often tend to widen rather than close the gaps in the distribution of income. This is a general problem faced by most countries in formulating policies dealing with agriculture. Tax and transfer policies (**52**), including income and inheritance taxes and tenure policies (**53**), can be used to bring about the desired inter- and intra-agricultural income distribution.

One can argue with a great deal of justification that policies and investments affecting the environment within which agriculture operates contribute more to achievement of the national goals by agriculture than many of the policies and investments that could be directed specifically to the agricultural sector itself. As the ratio of nonfarm to farm population increases and agriculture becomes more commercialized, infrastructural investments (**54**) supporting agriculture and its urban markets must increase. To increase the effectiveness of production and marketing of agricultural products, infrastructural investments in transportation and communication (**55**), rural electrification (**58**), marketing (**60**), and credit (**61**) institutions and systems become crucial. In addition, as farmers and rural people see many of the advantages afforded their urban cousins, they also become more interested in contributing to their own personal well-being and to that of their children through better medical, health, and sanitation facilities (**57**); cultural activities (**63**); educational opportunities (**59**); environmental quality (**56**); and investment in their general welfare (**62**). Some of the infrastructural improvements indicated are not normally considered in analyses of the agricultural sector, in part because they fall outside the scope of responsibility of the agricultural ministry in most countries.

It is difficult to treat the subject of personal freedom (**67**) empirically as a component contributing to the quality of rural life, but it should be an implicit consideration in the formulation of policies and programs designed to develop the agricultural sector. Such policies and programs should be based upon consideration of their consequences upon rural people's freedom of choice (**68**), their freedom and level of opportunity (**69**), and equity (**70**). Further, farm management and marketing decisions are more likely to reflect better use of resources if farmers and marketers responding to their environment decide what actions they will take, rather than being directed in their actions.

Agricultural Contributions to General Economic Development

In addition to food supply, most nations' agricultural sectors are expected to make other contributions to the development of the nonfarm economy. Figure 13 diagrams some of the interactions among valued



G. 13. Agricultural contributions to general economic development. (Numbers ı the right corners refer to those boxes in either figure 11 or 12 and indicate ıkages necessary to complete the line of reasoning.)

contributions and means of obtaining them. General economic and social development can be enhanced through increases in gross national product (GNP) (**71**), improved urban quality of life (**78**), and a favorable balance of payment situation (**85**). The agricultural sector can contribute to these components in a number of ways.

Total GNP (**71**) can be increased through increasing agricultural GNP or by increasing the value of agricultural production (**72**). One means for increasing the value of agricultural production has already been diagrammed in Figure 12, starting with block (**24**). The other means for increasing total GNP is to increase nonagricultural GNP (**73**).

Agriculture can contribute to the increase in nonagricultural GNP through providing agricultural production inputs into nonagricultural industries (**75**) such as canning companies, meat processing firms, and milk and dairy product processing plants. Another means is through supplying excess labor from rural areas to urban industries as urban industrial jobs become available (**76**). Still another way is through increasing the use of purchased inputs (**77**) in agriculture, provided these inputs are produced in the domestic, nonfarm economy. Finally, with the transfer of people from rural to urban areas, it can be expected that some wealth will transfer as a part of the migration process, including proceeds from the sale of farms or the inherited share of farm businesses. These assets from the agricultural sector can be provided as direct investments (**74**) to the urban sector to increase industrial capacity to produce goods and services and nonfarm GNP.

There are a number of means by which the quality of urban life (**78**) can be enhanced, such as increasing urban investments in infrastructure (**80**), investments in environmental quality (**81**), and increases in the degree of personal freedom allowed (**82**). As urban centers become larger, more concentrated, and congested, population dispersion policies (**79**) and rural industrialization (**84**) become necessary for potential rural-to-urban migrators to find job opportunities without migrating. Another prerequisite for population dispersion and probably even for rural industrialization is the expansion of the rural infrastructure (**83**) already discussed. Urban environmental quality can be enhanced through population and industrial dispersion policies that provide for the improvement of air (**64**) and water quality (**65**).

A great deal of attention should be focused on the problem of waste disposal and recycling in both rural and urban areas (**66**). Another means by which the agricultural sector contributes to general social and economic development is through helping maintain an acceptable balance of payments (**85**) in a nation's economic relationships with the rest of the world. The three main components of the balance of payments are exports,

imports, and long-term capital flows. Long-term capital flows (**88**) must be rationalized over time to contribute to balance-of-payment stabilization. On the trade side there are two ways to avert a balance of payment deficit — increased exports (**86**) and decreased imports (**87**). In terms of the agricultural sector, exports can be increased through increasing domestic agricultural production. Agriculture can contribute to increased exports also through the means discussed above in increasing nonagricultural GNP, again coupled with policies promoting exportable production (**90**).

Other means of stabilizing the balance of payments is through a decrease in imports. Imports can be decreased, or at least increased at a slower rate, by policies that decrease the rate of population growth (**92**). A more effective way might be through increased domestic agricultural production (**91**) that stresses policies which contribute to increased production of import-substitution products. The same argument can be made for increasing nonagricultural GNP by providing resources to the nonfarm economy for import-substitution production (**93**). This assumes that the increase in export plus import-substitution production is greater than the increased import-plus-export diversion, because of larger per capita incomes and the marginal propensities to consume and import.

Administrative and Political Considerations

A prerequisite to agricultural sector development is governmental organization and administrative structure at all levels that are flexible and responsive to the needs of rural and urban citizens. Choices must be made, complementarities exploited, conflicts resolved, and policies executed in a manner designed to achieve goals with the physical, human, technical, and institutional resources available, a minimum of adverse economic and social consequences, and both short-run needs and long-run requirements considered.

Effective administration of agricultural development policies, programs, and projects involves, among other considerations, the values of:

1. Coordination of decision-making and planning responsibility, with administrative control of persons and agencies executing the decisions
2. Reliable sources of information on the performance of those executing the decisions and of the phenomena being controlled
3. Sufficient insulation of the administration of technical and economic agricultural systems from the political arena to permit such systems to function without political disruption
4. Provision for technical agricultural competence to influence the planning and administrative processes at all levels
5. Analytical capacity to take into account the full range of relevant

information, using the full range of available techniques, as appropriate and uncontrolled by administrative and political personnel

Policy Choices

The job of the planner and the policy maker is to determine the weighting of the values to be attained, both among and within the value sets considered. More weight may be given to those instrumental values or means that contribute to attainment of a larger array of more basic values and less weight to those that produce fewer "goods" or more "bads" as a by-product of the "goods." Establishment of the weights requires a synthesis of the kinds of normative knowledge described in this chapter and positive knowledge describing the system under consideration and how it works — in this case, the agriculture sector. With this synthesis, the decision maker can proceed to the establishment of realistic and relevant goals and prescribe the right actions required to achieve those goals.

In making these decisions, the decision maker must be cognizant of the time and adjustment path, as well as the ultimate consequences of his actions. Some policy choices, such as land reclamation or population control, may require large initial investments, with long delays before the benefits are realized, whereas the effects of other policy actions, such as price controls or embargoes, are immediate. Some policy choices may have short-run benefits without lasting value if they treat only the symptoms of disequilibrium resulting from fundamental structural change in the economy. To make the appropriate choices and determine the right actions, decision makers require a continuous analytical input into the decision process.

4
Theory and Practice of Model Building and Simulation

Thomas J. Manetsch

INTRODUCTION

A major purpose of this chapter is to provide a specific but relatively nontechnical description of the rather involved processes that lead to formal models for use in addressing sets of problems in a subject-matter modeling context or specific problems in a problem-solving modeling context. The material discussed should be of use to at least three distinct groups of people:

1. Decision makers who need some understanding of these processes to make informed use of models as aids to decision making
2. Nontechnical administrators, who are related in some way to a system simulation team responsible for developing and maintaining subject-matter and decision-oriented problem-solving models
3. Members or potential members of a system simulation team who need a nontechnical orientation to the model-building process

The model-building process is more-or-less general in nature; that is, the steps involved in model building are likely to be about the same whether the model is for use at the enterprise level — for example, to aid a farmer in making planting decisions; at the subsector level — for example, to aid government in arriving at decisions for regulating commodity prices; or at the sector level — where a myriad of decisions influence many important aspects of rural and national life. The discussion that follows, therefore, applies to a range of model-building situations.

Decision making at various levels in agricultural development is always subject to error. Uncertainty with respect to weather, prices, or basic information describing the nature of the system being managed guarantees that decision makers cannot always make the "right" or "best" decisions. Good models aid in decision making by improving the quality of decisions and increasing the probability of decisions leading to "right" actions — but that is all they can do. A key qualification in this last statement is that the model in question be a "good" model. The discussion that follows will help the reader to know a "good" model when he sees one.

There are three major tests of a "good" model. The first is at the level of problem definition. At this stage a model must be addressing the right problem or set of problems. It must accept the right variables as policy inputs and produce the right variables for enabling decision makers to evaluate alternative policies. The second major test of a "good" model is the quality of its mathematical structure as an approximation of the real system of interest. In most practical decision-making situations, the system is complicated enough mathematically to require that it be solved by computer. This gives rise to a computer model that approximates the mathematical model that approximates the real world. The third test of a "good" model, then, is how well the computer model approximates the mathematical model. Other model-related problems such as bad data or inaccurate interpretation of the model's results are deferred to later chapters.

THE MODEL-BUILDING PROCESS

In this section we consider key aspects of problem definition — the logical starting point for any modeling activity. We then survey model-building approaches and describe the process whereby large subject-matter or decision-oriented models are built from components using the "building block" approach. This section concludes with a discussion of some coarse checks for validity of the mathematical model with respect to its internal logical consistency.

Problem Definition

Problem definition is the process whereby precisely what a model must contain and do is specified in order to address meaningfully the important policy questions under consideration. Much has been written about this important issue [14, 32, 126, 127], and we will only present an overview of key points. It is very important to understand at the outset that there is more to problem definition in a practical, decision-making situation than is described here. Formal models are but one input to the decision-making process, and problem definition, in a larger sense, must lay the groundwork

for all the activities needed to arrive at sound decisions and their implementation in the real world.

In order to lay a foundation for a model that will meaningfully address decision questions, problem definition must include the following:

1. Assessment of the various goals that are to be satisfied as a result of the decisions to be taken (stated in other terms, determination of the objectives sought, e.g., increases in farm income, equitable income distribution by particular regions and social classes).
2. Explicit definition of the boundaries of the system being managed. (Loosely speaking, this determines the range of factors that must be considered in arriving at decisions.)
3. Determination of the various, specific performance criteria the model should produce in order to enable decision makers to properly evaluate alternative courses of action. Examples of such criteria include per capita incomes (perhaps by specific regions and/or social classes), contribution to GNP, foreign exchange earnings (or deficits), costs of government programs, measures of human nutrition, and costs or revenues to government as a result of various policy actions. Complete specification of these criteria also requires definition of the units of measurement desired and the time frequency required — yearly, quarterly, etc.
4. Explicit and exhaustive specification of the decision variables that can be exercised in attaining the goals sought.

To define a problem well is one of the most challenging phases of model building. It requires the accumulation of much information; the analysis and synthesis of information to isolate that of significance; and, most importantly, close cooperation and interaction between decision makers and model builders.

Model Types

A good problem definition will provide a framework within which an appropriate model can be developed. Several types of models can be built, and a well-defined problem can help in determining which type is best for the situation at hand.

Models can be classified according to the view they take of the real world: microscopic or macroscopic. Microscopic models take a very detailed view of reality and represent individual entities moving through, or being processed by, the system. For example, a detailed model of the operation of a grain storage system would represent each individual shipment of grain as it was loaded or unloaded at the storage facility. A macroscopic (or aggregative) model, on the other hand, deals with aggregative flows of goods or services; for example, aggregated birth and

death rates in a population or total production of a commodity in a geographical region. A good problem definition will help us decide which of these models to build. Some problems require a microscopic point of view; for others, a macroscopic model is clearly more appropriate.

A second important way to classify models is by whether or not they represent dynamic phenomena in the real world. A good test to determine whether a given system or situation is dynamic is to pose the question, Will actions taken today influence the future in some way that it is important to assess? If the answer to this question is yes, we are dealing with a dynamic system or situation. Clearly, development is a dynamic process, and in many areas dynamic models are needed to deal with development problems adequately. Dynamic models are usually constructed using differential or difference equations[1] because such equations are able to project into the future the approximate consequences of decisions taken at the present time.

A nondynamic model is a static model. Static models are incapable of providing information about the future consequences of current decisions. They are constructed using algebraic equations — equations that do not contain past values or rates of change of system variables. Static models, too, can be useful in addressing decision problems in agricultural development. For example, a static model may be able to tell a farmer how many acres of various crops he should produce this year, given particular assumptions about prices and yields per acre.

A third important way of classifying models is according to whether they are deterministic or stochastic (random). A stochastic model contains random elements that cloud the model's outcomes with uncertainty. Deterministic models are appropriate when the effects of stochastic elements are small or negligible; i.e., deterministic models do an excellent job of predicting where in space the moon and planets will be at some future time. In most development problems, however, randomness in variables, such as prices and weather, has a substantial impact on the outcomes of interest in decision making. Deterministic models are sometimes used, even in these cases, to tell what is likely to happen if all random factors take on their average values.

Stochastic models approximate the effects of random factors and provide decision makers with some idea of the range of outcomes that are possible from a particular decision. In order to do this, models are operated repetitively in a so-called Monte Carlo mode. In each Monte Carlo run of the model, the random factors involved are allowed to take on a different set of values that are consistent with the randomness inherent in the real world. The results of Monte Carlo analysis with a stochastic model might be something like the following (oversimplified) example:

(1) Decision Alternatives	(2) Expected Outcome (Benefit in Appropriate Units)	(3) Range of Outcomes
A	2,500	1,900–3,000
B	3,600	2,800–4,200

These results are interpreted as follows. The average or expected benefit from decision alternative A is likely to be 2,500 units (thousands of dollars, say), and the probability (say .95) is that the actual benefit will be between 1,900 and 3,000 units.[2] A similar interpretation applies to decision alternative B. In this case alternative B is likely to be better than A, but there is some (small) chance that A may turn out better than B. Monte Carlo analysis can easily be extended to the situation where decisions affect a number of criteria that must be evaluated. Although operating stochastic models in a Monte Carlo mode provides additional information for decision makers, operating costs are increased. It simply takes more computer time to assess the possible range of outcomes when random influences are included in the model.

Another major model classification is that of optimizing versus nonoptimizing models. An optimizing model gives a decision maker information describing the courses of action that will lead to the optimization of a particular criterion. Most optimizing models can do this subject to constraints which ensure that other criteria are at prescribed levels or within prescribed bounds. Nonoptimizing models simply indicate what outcomes, as measured by various criteria, are likely to result from alternative decisions.

Models can be classified in several other ways, but they are not of central importance to this discussion. A model's type greatly affects its capability, the cost of its development, and the cost of its operation. In light of the substantial model development and operating costs that are possible in large applications, the choice of model type is important. The following generalities can assist in this decision:

1. Dynamic models are usually more costly to develop than static models. However, they usually provide decision makers with significantly more useful information.
2. Micro models are not necessarily cheaper to build than macro models (even though much more limited in scope) because they often contain elaborate detail.
3. Stochastic models usually are not much more expensive to build than deterministic models, but they are much more expensive to operate.
4. Optimizing models are usually much more expensive to operate than nonoptimizing models.
5. The cost of operating a nonoptimizing model usually goes up directly

with the size of the model (as measured by the number of variables contained in the model) — double the size, double the operating cost.

6. The cost of operating optimizing models tends to go up much faster than the model size — double the model size, quadruple the operating cost (perhaps).
7. Model development costs tend to go up much faster than the model size — double the size, quadruple the cost (perhaps).

Obviously, important decisions are necessary regarding the type of model to construct. On the basis of the four two-way classifications discussed — macro-micro, static-dynamic, deterministic-stochastic, optimizing-nonoptimizing — there are potentially 16 distinct model types that can be constructed. Careful thought and selection at this point can pay significant dividends in terms of reduced model costs and, ultimately, in the model's effectiveness as an aid to decision making.

Modeling Approaches

After the broad outlines of the system model have been established as a result of sound problem definition and the most appropriate model type selected, two major approaches to model building can be employed singly or in combination: the so-called black-box and structural approaches. Essentially the black-box approach seeks to identify a system model from data describing the past behavior of the real-world system. Through various statistical and mathematical techniques, a model is derived that in some sense is a "best fit" to the historical data but that does not necessarily represent real causal relationships in the system. This approach has developed independently in the social and physical sciences. The field of econometrics is [92] representative of the social science stream of development, and much of the work done in system identification [60] in various areas of engineering employs black-box methods. This method has been used extensively in agricultural development, for example, to specify mathematically how producer supply and consumer demand [92] are likely to change in response to factors such as market prices and income levels.

The structural approach to model building attempts to represent or simulate the detailed system structure that causes the total system to behave as it does. This approach decomposes a system into its component parts, builds mathematical models that approximate the behavior of those component parts, and then interconnects the component models to obtain a model of the overall system. For example, a structural model of a domestic commodity market would develop component models that represent the behavior of producers, middlemen, and consumers. These com-

ponent models might contain considerable detail in representing crop production and transportation processes and decisions that manage stock levels and determine commodity purchases and sales. Many, if not most, large-scale decision models are developed with the use of this approach aided by the black-box approach to fill in certain parts of the structure [51, 127].

These two basic means of constructing system models should be regarded as complementary — each possessing unique capabilities and limitations. For example, the black-box approach is based on past observations of an existing system and cannot be used in designing a new system that does not yet exist. On the other hand, in certain management problems the task at hand is to manage an existing system whose inner workings are unknowable. In this case, the black-box approach is the only recourse. In summary then, the nature of the system will determine which of the approaches should be applied or in what combination both should be applied. Clearly, use of the two approaches together brings more information to bear on the modeling problem and will generally lead to better models than either approach alone.

Definition of Model Components

As implied above, most models of complex, real-world phenomena are best broken down into a number of interconnected submodels or components. There are several advantages in doing this. In the first place, this can lead to a natural division of effort within a model-building team. People within the team can be assigned a component with which they are well equipped to deal by virtue of training and experience. Further, it is usually more economical to develop and test a large model component by component, since large models are normally cumbersome and difficult to develop. A final advantage of building models from so-called building blocks is that in some cases it is possible to use previously developed components for parts of the total model structure. Examples of model components in an agricultural sector model are agricultural production and consumption (perhaps disaggregated by regions, farm size, etc.), private marketing and transportation, government marketing and transportation, and urban consumption (perhaps disaggregated by region and/or income class).

With all its advantages, this building-block approach is not without its problems and must be carefully implemented. A key step is the appropriate definition of the model components. If components are inappropriately defined, a simulation team will find itself working at cross purposes and wasting considerable time and resources. Adherence to several basic principles will help in the definition of "appropriate" model components

and reduce the likelihood of wasted time and resources in model building. The following are helpful principles:

1. The boundaries of each component must be carefully defined in terms of the input variables it must receive and the output variables it must produce. These variables must have common units of measure in each component and timing must be compatible among components (monthly, quarterly, etc.).
2. Components must be defined so that all variables required as inputs are either produced as outputs from other components or specified externally (exogenously). For example, world commodity price projections would be external or exogenous variables for a national or agricultural sector model.
3. Model components must be defined so that the structure of one component is independent (or nearly so) of the structure of other model components. If this were not the case (and it isn't automatically the case), the modeler of each component would have a "moving target" that depended upon what other model builders were doing. For example, in a model of a farm-firm-household, it would be inappropriate to have production decision, consumption decision, and investment decision components, since all these decisions are interrelated. It would, however, be appropriate to have a "decision" component that embraced all these areas.

Developing Component Models

Given that model components are well defined and input and output variables are explicitly specified, the next question is how the component models are explicitly developed in terms of mathematical equations. Although model building is an art acquired by experience — the art of creatively describing real-world phenomena by mathematical abstractions — there is a backlog of previously developed model "archetypes" upon which the model builder can draw. The model archetype appropriate in a given modeling situation is, of course, determined by the type of model that is needed to address the relevant real-world problems. We will, therefore, discuss model archetypes in association with the model type or types to which they pertain.

The so-called conservation of flow model archetype is fundamental in importance because it applies to most dynamic models. This archetype is simply a mathematical statement of the principle that matter and energy cannot be created or destroyed. Examples of applications of this model include inventory-like processes — any difference between flow in and flow out is made up by a change in the level of stock stored in the "inventory." Specific applications include modeling commodity storages

at farm, marketing, and consumption locations; modeling cash flows and cash balance (the inventory); and modeling populations of people, animals, etc. (the number of people, cattle, etc., in a given age-sex class is an inventory level).

Another important model archetype that is applicable for many dynamic models is the "cybernetic" model [46]. Cybernetics is the science of control, and the cybernetic model applies whenever the deviation between the desired and actual value of a quantity is used to change the quantity in the desired direction. There are many applications of this principle in agricultural sector models. For example, subsistence farmers, to some extent, base their commodity sales decisions upon the difference between their current commodity stock levels and the level desired to feed the farm family until the next harvest period. Or, in implementing a price regulation program, a government may purchase or sell in the domestic market, depending upon whether the market price is below or above the desired or target price. (Further, the amount of purchase or sale is usually in proportion to the difference between actual and target price.) The cybernetic model is useful in developing models of such phenomena when they occur or when their occurrence is desired in the real world. There are many important applications of cybernetic or control theory in agricultural sector modeling, and the "complete" model builder should be well versed in this field.

Other model archetypes useful in structuring dynamic models are two classes of time delays. The first is the so-called discrete or pure time delay [126]. These delays generally are used in micro-level models to represent mathematically the time lags inherent in human decision making, transporting a unit of goods from one point to another, providing a service, producing a unit of output, and so forth. The discrete delay is also used in the development of models that simulate the age and sex distribution of populations (people, animals, trees, etc.) over time [6].

The second important class of delay is the distributed delay [7], also called the continuous delay. This delay has proven very useful in developing mathematical models of aggregative (macroscopic) delay processes. It has been used, for example, in modeling aggregate lags in production, consumption, transportation, and capital formation. In other words, this model archetype is useful in simulating lags in aggregate variables which are streams of goods and services originating from many sources at the micro level. This delay concept has also been used in population models of trees and animals, where it is important in simulating output over time to keep track of the number of entities in the population that are at various levels of maturity [5]. Distributed delays are represented mathematically by differential equations, whereas discrete delays are described by differ-

ence equations. System modelers should be well acquainted with these types of equations and their real-world significance, solutions, and solution properties.

We have been discussing model archetypes that are useful in describing dynamic systems. Another in this category is the so-called queueing model [174]. The queueing model is used frequently to represent stochastic microscopic processes that are dynamic in nature. A basic queueing model is composed of a "service station," which processes individual system entities with a random service time, and a "waiting line" of entities waiting to be served. Queueing models are useful in designing efficient systems that have these characteristics. An application of a queueing model might be the off-loading of grain at an elevator or port. In this case the service station is the off-loading equipment and the waiting line is the group of trucks or ships waiting to be off-loaded.

Another type of model that may be used in some cases to represent dynamic systems is the so-called simultaneous equation model [92]. This model is also used in some cases to represent static systems. Such models result from application of the black-box approach in that they are derived from past data from the real world. In the case of dynamic simultaneous equation models, a set of difference equations is determined that results in a "best fit" to the historical data from the real world. Econometric methods are important here, and the model-building team should include one or more persons with expertise in this area.

Model archetypes that are normally used in the construction of static models are also important. One such archetype is the "input-output" model [11]. The input-output model has been used extensively to study interactions that take place among the sectors of an economy (or the subsectors of an agricultural sector). With such a model it is possible to determine the changes in flows of goods and services in an economy (or sector of an economy) that must take place in order to sustain particular development goals; for example, to expand output of certain commodities. Because the basic input-output model, as such, does not model the process whereby the system moves from one operating condition[3] (equilibrium) to another, it offers little insight into how to move the system behavior in desired directions. It does, however, provide useful information on the feasibility and characteristics of different operating conditions. With additional effort, a basic input-output model can be made dynamic and thereby made to provide information for determining investment and other policies that can move the system to some desired future operating condition.

The linear program [174] is another model archetype that is often used to address static questions. The linear program is an optimizing model that

is frequently used to indicate to decision makers the mix of input resources that will optimize some single criterion of interest (production cost, net profit, and so on). This model has been used extensively at the farm level to guide the allocation of land, labor, and capital to various production activities that are subject to a variety of constraints on inputs and outputs. It has also been used in agricultural sector models (including the Korean model) to approximate the way farmers, in the aggregate, respond to changes in input and output prices, interest rates, and other variables that are influenced by policy actions. Like the input-output model, the linear programming model can also be made dynamic through so-called recursive linear programming. Members of the model-building team should be skilled in the use of both input-output and linear programming models.

The available model archetypes discussed above can be useful in structuring components of larger models. In smaller applications, however, the component may be the total model used in decision making. Models and model components may include a number of the model archetypes. Attention is now turned to other raw material that is often useful in structuring component models. The contributions of disciplines from the social, biological, and physical sciences are discussed.

Role of Disciplinary Inputs in Component Modeling

An important discipline in model building is the social sciences. The contributions of economics to the construction of components for agricultural models are quite extensive. Only a brief overview will be provided here. Many decision-oriented models are faced with the problem of modeling the likely consequences of policy actions upon a system that contains a number of private decision makers, each of whom has some freedom to behave autonomously. Economic theory can provide us with information useful in developing models that can approximate the behavior of these private decision makers in response to policy actions. Models constructed on the basis of theory must always be tested for credibility, but the theory often provides a useful starting point.

Economic theory has provided a useful framework for modeling farm-level decision making in production, consumption, and investment. Although much more work remains in this area, the farm-level linear programming model cited above is one application to date. In certain applications, such as the Korean grain management model (see chapter 14), it is important to be able to simulate approximately the decision making of private middlemen as they buy, sell, and manage their stock levels in response to prices, interest rates, and other relevant variables. The grain management model has used economic theory extensively in modeling this kind of behavior; but, again, much more work is needed in this area. A

third major area in which economic theory can contribute to model building is in modeling consumer demand as it responds to changes in factors, such as commodity prices and per capita income levels.

Demography, the study of human populations and how they change with respect to size and age composition, is obviously of key importance to agricultural sector modeling. An important related topic is rural-urban migration. Some of the work in the social sciences is providing a better understanding of this phenomenon and creating a basis for more complete modeling. Still another contribution of social science, through sociology, is in understanding and modeling attitude change, particularly as it relates to adoption of new technology in agricultural development. Other important disciplines from the social sciences contributing to the modeling process include political science and public administration, industrial psychology, and law.

Another discipline important in structuring agricultural models is the biological sciences. Since many of the processes we seek to manage effectively in agricultural development are biological in nature, it follows that we must have reliable models of these important biological processes. Of particular importance are models that describe effects of different input allocations on the outputs of annual and perennial crops and various livestock. Although progress has been made in these areas, much work remains in expanding knowledge to develop such models. The issue is complicated. In many cases, particularly in models of perennial crops and livestock, challenging problems in systems science arise in adequately modeling dynamic aspects. In any event, the simulation team must include people who can bring biological science — particularly crop science, animal science, and ecology — into the modeling process.

Physical science is another discipline important in constructing various kinds of agricultural models. In particular, now that energy has become a significant constraint in development, it is clear that much more needs to be done to assess the energy requirements of alternative policies. This can take place only if the simulation modeling team avails itself of appropriate disciplinary knowledge from physical science.

A variety of important disciplinary inputs must be brought into the model development process. These inputs can be provided by the simulation team members themselves, by the use of special consultants, or, in most cases, by both these means. We turn our attention now to the final step involved in structuring a mathematical model before the mathematical model is ready to be implemented on a computer.

Final Step in Mathematical Model Development

Given that component models have been well defined and developed in terms of specific mathematical equations, it is usually a relatively simple

matter to link the components together by appropriate mathematical equations. In many cases linking components together requires simple equations that equate component output variables to the appropriate component inputs to which they apply.

A final logical step before computer implementation is a coarse check on the validity (coherence) of the model. Some key questions to ask at this point are:

1. Does the model contain the major variables thought to be relevant in the given application (appropriate policy inputs, criteria for evaluation of performance, etc.)?
2. Is each model variable uniquely defined (defined once and only once)?
3. Is each equation consistent with accepted theory and constraints that may apply?
4. Is each equation mathematically correct?
5. Have components been properly linked?

These checks on the model's validity are never sufficient, but they are a necessary beginning. Further discussion of the important matter of model validation and verification (coherence and correspondence) is found below, where the question logically comes up again — after computer implementation of the mathematical model.

COMPUTER IMPLEMENTATION OF THE MATHEMATICAL MODEL

For all but the simplest mathematical models, it is necessary to use a computer to "solve" the model. By solving the model, we mean determining the logical consequences, as indicated by the response of the performance variables, that follow from the model structure, its data, and the policy and other inputs that have been specified. The objective of computer implementation is to develop a computer model that will indicate how the system performance variables (those variables used by decision makers to evaluate alternative policies) are affected by changes in the policy inputs or changes in the model structure. It should be reemphasized that there is almost always error in the computer model. That is, the solution of the computer model is rarely, if ever, exactly equal to the true solution of the mathematical model. An important task of computer implementation is, therefore, to ensure that this approximation error is small enough to be neglected.

Before or in the early stages of computer implementation, data must be acquired that permit assigning values to the parameters or coefficients of the model and initial values for certain (state) variables. Included here might be elasticities that specify changes in demand or supply that take

place because of changes in prices and income; coefficients that define the input requirements of various production processes, land areas, sizes of human and livestock populations, perhaps on a regional basis; parameters that determine population birth and death rates, and so forth. Econometric and other estimation methods from statistics and systems science are important. It should be emphasized that data and estimates obtained therefrom are usually tentative at this point. Experience in testing the computer model often leads to insights into high-priority data needs that can guide further data collection and improvement in the data base of the model.

Choice of Programming Languages

A fundamental decision to be made early in computer implementation is the choice of a programming language for the model. First, a broad decision must be made whether to use a general-purpose computer language such as FORTRAN or a special-purpose language such as DYNAMO [146], GASP [145], or GPSS. The advantages of a general-purpose language such as FORTRAN are adaptability to many model archetypes and computers and relatively economical model operation in terms of computer costs. Disadvantages include more difficulty (and higher costs) in programming, in part because of the extra programming work involved in making computer results easily interpreted by the user. Special-purpose languages, on the other hand, are much easier to program and usually have special output routines to aid the user in interpreting results. Disadvantages of these languages are often higher model operating costs and limited adaptability to model archetypes and computer types.

In specialized applications the special-purpose languages are a logical choice; however, experience has shown that in large agricultural sector models, a general-purpose language is often the only viable choice. The wide range of model archetypes employed is often the determining factor, though transferability of the model and its components among countries and computers can be a deciding factor. FORTRAN was the programming language chosen for both the Nigerian and Korean simulation models [116, 151]. The programming task in both cases was eased significantly by the use of special-purpose, FORTRAN-compatible software packages to handle, for example, linear programming, user-oriented tables and graphs, and basic simulation operations [7, 9, 122]. Clearly, a simulation team is well advised to equip itself with the expertise and software necessary to use general- or special-purpose programming languages as particular applications warrant.

Choice of Computational Techniques

In system simulation there are significant decisions to be made in the choice of computational techniques used in the computer model. Proper choice here can lead to substantial savings in the time and cost of model development.

In almost every simulation model there is a need to represent the relationship between two variables or quantities in language a digital computer can understand. These relationships or "functions" can be represented in several ways. A very common and efficient means of doing this is the so-called straight-line approximation method, illustrated in Figure 14.

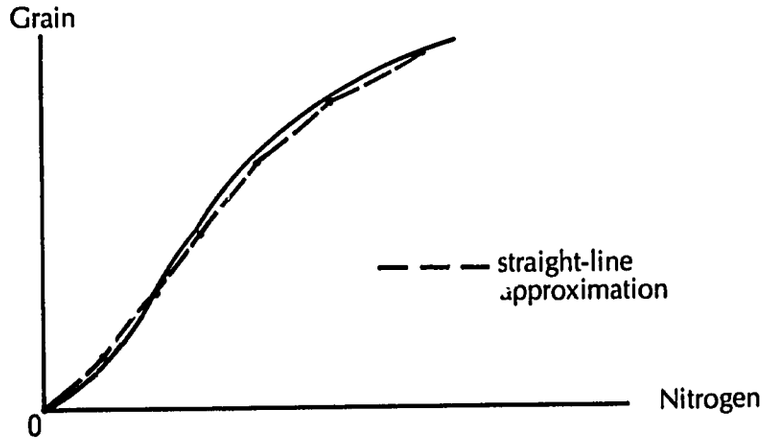


FIG. 14. The straight-line approximation method of function representation.

This figure illustrates a production function relating quantity of grain produced to quantity of nitrogen available. The dashed lines in the figure show a straight-line approximation to this production function. A number of excellent special-purpose computer routines are available for efficiently carrying out straight-line function approximations in simulation models [9, 122]. In some cases the functional relationship between two variables can

be implemented with functions built into a programming language such as FORTRAN (examples are logarithmic, exponential, and trigonometric functions). Programming using "built-in" functions is easier, but it almost always uses more computer time than the straight-line approximation method described above. Another method of function representation, polynomial approximation, can be extended to functions of more than one variable but is less common than the two methods cited.

When the system model contains differential equations, an important choice to be made is the type of integration procedure to use in solving the differential equations. Differential equations are solved on a digital computer by the process of numerical integration; there are several ways to do this, each with its own advantages and disadvantages. The simplest and most common numerical integration technique in agricultural models is the so-called Euler (pronounced "oiler") integration. It is very easy to program in complex models and is reasonably efficient in operation. Euler integration is the simplest member of the "predictor" family of integration methods. Higher-order predictor methods can be used in certain situations and can result in models that operate more efficiently but are more difficult and expensive to program. If great computational precision is sought (which it seldom is in agricultural models), the "predictor-corrector" or Runge Kutta methods of solving differential equations would be appropriate. Recall that the important distributed delay model archetype is structured using differential equations. A number of efficient computational packages have been developed for readily implementing distributed delays on digital computers [5, 7, 122]. These can save a great deal of programming time, and a simulation team should have access to them.

Other computational packages can also aid significantly in implementing mathematical models on digital computers. Along with computational packages for implementing distributed delays, there is a corresponding set for implementing the discrete delays [6, 122]. Further, packages are available that interconnect delay models to provide more complex packages useful in implementing population models [5]. These have been used extensively to simulate populations of humans, trees, animals, and such on a digital computer and are often important components in larger agricultural models.

Another important group of computational packages makes it possible to incorporate optimization readily into models. In certain kinds of decision situations, it might be of interest to seek policies over time that will optimize some specific criterion of interest to decision makers. Linear programming models have been used extensively to solve specialized kinds of optimization problems (usually static). A number of packages are available for doing linear programming; however, great care should go

into the choice of a particular package for a particular application, since there can be large differences in computer operating costs with different linear programming packages. Recent developments in technology [26, 27, 111] have made it feasible to solve certain kinds of dynamic optimization problems using simulation models. Using this approach, it might be possible, for example, to find a set of government commodity purchase and release policies that would attain some prescribed commodity price targets over time at a nearly minimum cost to government. Solving these kinds of optimization problems can involve substantial computer time and cost but may be worthwhile in certain decision-making applications. These various optimization packages are sometimes used to simulate the optimizing or quasi-optimizing behavior of components (i.e., farmer behavior, merchant behavior) in agricultural models.

It should be clear that many computational packages are available that can aid significantly in computer implementation of mathematical models. It is economical to store a wide variety of these on magnetic tape or other permanent storage, which can make them readily available to a simulation team.

Preliminary Tests of the Computer Model

Certain tests should be carried out with the computer model to ensure that it provides an acceptable solution to the system mathematical model. Since the computer model approximation of the mathematical model is normally used to address the more fundamental issue of how well the mathematical model represents the real world, the adequacy of the computer model as an approximation to the mathematical model must first be established. Because of the wide variety of model types, it is not possible to provide an exhaustive discussion of possible tests of computer models. Discussion will be limited to the most common tests that apply in a number of cases of interest.

One useful set of tests involves operating the computer model under conditions for which the solution of the mathematical model is known. If the computer model produces an acceptable approximation of the known solution under these conditions, we have evidence of its acceptability. It is sometimes possible to check the computer model against a number of these known solutions to provide considerable evidence regarding its acceptability. As an example, we may know that under certain extreme supply-demand conditions (in the mathematical model) supply should increase to limits determined by production and other constraints and that market price should stabilize at some high level. The computer model could be tested under the same conditions to determine whether or not it exhibits the required behavior.

A second set of tests determines whether or not the computer model satisfies a number of constraints that are built into the mathematical model. Included here are the conservation of flow and energy properties mentioned earlier and cost accounting identities (a special case of conservation of flow). Thus, a population model could be checked to ensure that the births, deaths, and migrations were in accord with changes in the sizes of population groups. In other cases we may know that certain variables in the mathematical model must behave in a prescribed manner. For example, prices must always be greater than zero. It is an easy matter to check such conditions in the computer model.

In models involving differential equations, there is another important test to be carried out in the computer model. In most of the important techniques for solving differential equations on a digital computer, the error in the computer model decreases as the step size[4] decreases. The step size is the time interval between solution points as the computer model steps through simulated time. For example, the step size in a computer model may be one-twelfth year or one month. This means that the computer model computes model variables 12 times per year of simulated time. Mathematical theory tells us that in most cases the error in the computer model becomes very small as this step size becomes small. In these cases, then, the solution of the computer model should approach some fixed, limiting solution as the step size becomes small. The determination of an appropriate value for the step size in a computer model is an important decision. Improperly setting step size too large frequently causes the model to display spurious, unstable (explosive) behavior that only vanishes when step size is reduced to an acceptable value. The step size must be small enough to make numerical errors in the computer model negligible; but it should not be smaller than necessary, because computer operating costs increase rapidly as step size decreases. The cost of operating a computer model is directly proportional to the number of solution points, which is inversely proportional to the step size for a simulation over a given time horizon.

MODEL CREDIBILITY

Given that the computer model is an acceptable representation of the mathematical model, attention turns to the fundamental question of the adequacy of the mathematical model as a representation of those aspects that real-world decision makers are seeking to influence. In this section we will discuss some of the approaches that can be taken to establish evidence for the credibility of the mathematical model.

First, however, it should be noted that we are not dealing with a purely sequential process: model building — computer implementation — val-

idation — verification. It is, rather, an iterative process. Therefore, for example, during model validation and verification, flaws or weaknesses are often found that require modification or extension (more model building). In fact, several rounds of this kind of iteration are often necessary before a model is considered ready to use as part of the decision-making process. Also, the credibility of a model of a complex, real-world situation can never be established with absolute certainty. The best that can be sought is to not reject the model after applying the tests of coherence (validation), correspondence (verification), clarity, and workability as rigorously as possible. Significantly, even if a model exactly represented the segment of the real world of interest, this would not preclude the possibility of error in the use of the model in decision making. When the real world of interest in decision making contains randomness or uncertainty (i.e., is stochastic in nature), the best a good model can do is to increase the likelihood of making right decisions.

The checks for a model's credibility are discussed below in the order they are normally carried out in practice. This order is determined by the ease with which the various checks can be carried out. There is no point in carrying out costly tests of a model that may be rejected and modified on the basis of less expensive checks or tests.

The first tests for validity normally conducted on a model are the so-called logical consistency checks. These have been discussed above as tests of coherence and are usually carried out as part of model building and testing of the computer model. Given a model that has passed tests for logical consistency and tests that ensure that the computer model adquately represents the mathematical model, the model can be subjected to extensive sensitivity testing, the first phase of verification or correspondence testing. Sensitivity testing involves making significant changes in values of model coefficients or parameters, normally one at a time, and observing the changes that result in the key outputs of the model. Often the parameters selected for sensitivity analysis are ones for which we have the poorest estimates. The model at this point should have the best possible parameter estimates, given the data at hand. These sensitivity tests provide two important kinds of information. They indicate where we need to collect better data to improve parameter values of sensitive parameters that have significant impacts on model outputs of interest. This information leads to priorities and efficiencies in data collection. Further, these sensitivity tests produce changes in model behavior that we can check against our knowledge of how the model ought to behave under the given circumstances. This leads either to further confidence in the model or to refinements to correct deficiencies encountered.

Sensitivity analysis can also be carried out by making significant

changes in the policy inputs of the model. This provides further opportunities for checking model behavior; and, if carried out when the verification process is well along, it can provide useful insight into the most important policy inputs to consider during model implementation as part of the decision-making process.

As a result of extensive logical consistency and sensitivity tests, a model will be refined, more data will often be acquired, and the model parameter estimates will be improved. A model that has passed more-or-less successfully through these phases is a candidate for historical tracking tests. Such tests are also verification tests or, as discussed in chapter 2, tests of correspondence. If historical data are available that describe how the real-world system has behaved in the past, a dynamic model can be operated to determine how well it is able to reproduce this past behavior that has been observed. These tests are often rather expensive to conduct and should only be attempted after the preceding validation phases have been completed. Historical tracking tests will often result in further refinements of the model and improvement of data, and in additional evidence of model validation and verification to determine if the model is capable of reasonably approximating the past real-world behavior.

In some cases it is possible also to use historical tracking as a means of further refining estimates of selected model parameters. In this case suitable optimization techniques [111] are used to find values for these selected parameters that result in a "best fit" between model behavior and the past real-world behavior.

The ultimate test of the credibility of a model is how well it performs in practice in leading to more enlightened decisions that better serve the ends being sought. If a model has come through the above tests credibly in the eyes of the model builders and, in addition, has passed the test of clarity with the ultimate users of the model,[5] it can enter guardedly the decision-making process for its final test of workability A well-developed model will normally be able to make a contribution to the decision-making process. Use in decision making will proceed gradually, with the model gaining a more significant role as experience warrants. Thus, model application in decision making can be viewed, in part, as an extension of the credibility testing process.

A final comment on an important issue is necessary here before moving on to discuss model implementation in decision making: the need for clear and detailed documentation of the model. Models should be documented when they have been developed to the point where they can make useful contributions to decision making. Over time, documentation may be needed for several versions of a model as it evolves to meet the changing needs of the decision-making process. In many applications of models,

inadequate time and money have been allocated to model documentation, and the result has sometimes been waste of scarce resources when new model builders and programmers have had to pick up where others have left off. Good documentation of a mathematical model and its computer program should make it possible for new people to begin working with the model with relatively little consultation with the original architects of the model.

MODEL IMPLEMENTATION

Previous steps in the model-building process require significant interaction with decision makers, particularly in testing a model's credibility. Effective model implementation requires a high degree of intensive and ongoing interaction among decision makers, model builders, and the results of creatively designed model tests. This interaction process and how it can creatively lead to improved decisions is discussed below.

The interaction process can take place informally or through structured computer software; for example, a decision-oriented computer language, such as the policy analysis language (PAL) developed at Michigan State University [177, 178, 179, 180]. Informal model application takes place as an ongoing dialogue with computer results over an extended period of time. This dialogue often begins when knowledgeable persons (model builders and/or decision makers) design a small set of preliminary, alternative policies for attaining the goals being sought. These alternative policies become inputs to the computer model, and the results for the various policies are computed in terms of a set of performance measures (i.e., incomes per capita, foreign exchange position, costs to government, etc.) for each alternative policy. Normally different policies produce different mixes of benefits and costs, and these are subjected to critical evaluation by decision makers and others sensitive to the spectrum of needs that policies must address. Often evaluation of policies must include factors that are not included specifically in the formal model, and it is very important that policy evaluators have available information from other sources necessary to make such judgments.

Experience has shown that these evaluations of alternatives made explicit by computer models can lead to an improved set of policy options to be explored using the computer model. Model builders often play a creative role in the dialogue leading to improved policies and are also needed at times to adapt the model to respond to the new set of policy options to be explored. In complicated decision issues, a number of rounds of this kind of interaction may be required to arrive at an acceptable set of policy actions. These rounds of interaction using computer models can take place whenever it is appropriate to do so — as part of the budgeting

process, before key decisions, such as determination of price policies, or in the preparation of, say, a five-year development plan. Finally, this kind of ongoing model application can lead to a continual stream of model improvements as new information is acquired and as the needs of the decision-making process inevitably change over time.

In this interaction process it is important that the model display the consequences of alternative policies in forms that can be readily understood and interpreted. During model construction considerable effort often must go into the design of special tables and graphs that will readily communicate with decision makers and analysts. Although this interaction process has been described as involving mainly decision makers, analysts, and model builders, computer programmers also play a vital role in preparing the model policy inputs specified and in operating the computer model.

We have only briefly summarized an interactive process that can lead to creative contributions of models in agricultural planning and management. There are a number of important country-specific organizational and institutional questions that must be addressed in order to make viable application of a model feasible in specific decision-making situations. Suffice it to say here, the kind of close interaction described above is essential to fruitful model applications. If this potential is to be realized, organizational and institutional arrangements must be found which make this kind of interaction possible.

CONCLUSIONS

We have discussed in some detail the process leading to models that can play a useful role in agricultural sector decision making. Experience has shown that if this process is carefully carried out by skilled and experienced people, it can contribute to effectiveness in attaining objectives of the decision-making process over time. However, the converse is also true — ill-conceived models can waste scarce resources and contribute little to the decision-making process. The key seems to be a *skilled and experienced* model development team institutionalized as part of the decision structure. These important matters are discussed in part five of this book.

NOTES

CHAPTER 1

1. A large volume of publications, working papers, articles, and monographs were produced by the consortium. The summary and recommendations of the project, however, are contained in [85].

2. Public Law 480, The International Trade and Development Assistance Act of 1954, as amended, includes provisions for delivery of U.S. agricultural commodities (primarily grains) to qualifying developing countries on concessional terms. Governments of developing countries can in turn generate local currency revenues through the domestic sale of these commodities to be used for development purposes mutually agreed upon by the recipient government and the United States.

3. The Agricultural Planning Project agreement between the Republic of Korea's Ministry of Agriculture and Fisheries and the United States Agency for International Development served as the framework within which the Michigan State University field activities in Korea were carried out. The MSU Korean Agricultural Sector Study team (KASS) was originally supported under contract AID/ead-184 to complete the agricultural sector analysis report [151] and the investment priorities study [50] and was later supported under contract AID/csd-2975 for further development, testing, institutionalization, and utilization of the Korean agricultural sector model. A later direct contract between the Korean Ministry of Agriculture and Fisheries and Michigan State University using AID grant funds provided technical assistance to MAF in policy analysis, agricultural outlook, program and project evaluation, and agricultural statistics, as well as assistance in KASS model and investigative capacity institutionalization and utilization. This activity was the Korean Agricultural Planning Project (KAPP). Finally, an MSU systems scientist was retained under contract AID/ta-C-1322 to provide systems science input to the indigenous KASS team for an additional 18 months after the MSU/KASS team withdrew.

4. The "KASS team" was a combined MSU and Korean team making up the Agricultural Sector Analysis Division of NAERI.

CHAPTER 3

1. This chapter draws heavily on concepts found in [151], particularly chapter 5.

CHAPTER 4

1. Differential equations contain derivatives or rates of change of system variables. Difference equations contain past, as well as present, values of system variables.

2. In this case, the range 1,900-3,000 is called a "95-percent confidence interval for the outcome." Confidence intervals for other percentages can easily be computed from Monte Carlo analysis.

3. An "operating condition" is loosely defined as sets of input and output flows that are mutually consistent, given the input-output characteristics of the producing units in the economy.

4. This step size is often called Δt, DT, or "h" in the literature of simulation models.

5. Clearly, model users (decision makers) must have had sufficient experience with the model and the real world to make meaningful evaluation possible.

CHAPTER 5

1. Currently referred to in the literature as "rural development" or "integrated rural development."

2. Useable at the bureau level within MAF.

3. Gini ratios of .255 and .270 have been calculated for income distribution in the Korean agricultural sector for 1965 and 1974, respectively. Thus, Korean agricultural sector income appears quite equally distributed and is not growing appreciably more unequal over time.

4. The *Yearbook of Agriculture and Forestry Statistics* includes production statistics on more than 100 different crops and livestock numbers for 15 different species.

CHAPTER 6

1. In mathematical/programming notation, the sequence of operations in the migration mechanism for each mode is,

Mode 1: Exogenously Specified Overall Migration Rate

$$TMIG_t = \sum_{sex=m}^{f} \sum_{age=1}^{85+} RUMV(age, sex)*POPC'_t(age, sex, farm) \quad (1)$$

$$RUMF_t = TRUM_t/[TMIG/POPC'_t(total, farm)] \quad (2)$$

Mode 2: Labor Supply-Demand Mode

$$CMIG_t(age, sex) = RUMV(age, sex)*POPC'_t(age, sex, farm) \quad (3)$$

$$EMPMIG_t = \sum_{sex=m}^{f} \sum_{age=1}^{85+} [CMIG_t(age, sex)*CIV_t(age, sex)*EAPMV(age, sex)* UEMPR_t] \quad (4)$$

$$UEMDEF_t = DLNV_t - FLN_t - UEMPR_t* \sum_{sex=m}^{f} \sum_{age=1}^{85+} EAPNV(age, sex)* CIV_t(age, sex)*POPC'_t(age, sex, nonfarm) \quad (5)$$

$$RUMF_t = UEMDEF_t/EMPMIG_t \quad (6)$$

Transfer of Migrants

$$MIG_t(age, sex) = RUMV(age, sex)*RUMF_t*POPC'_t(age, sex, farm) \quad (7)$$

$$POPC_t(age, sex, farm) = POPC'_t(age, sex, farm) - MIG_t(age, sex) \quad (8)$$

$$POPC_t(age, sex, nonfarm) = POPC'_t(age, sex, nonfarm) + MIG_t(age, sex) \quad (9)$$

where:

CIV	=	proportion of a cohort that is civilian, civilians per capita, or civilians per migrant
CMIG	=	ex *ante* estimate of net number migrating from a farm cohort, migrants per capita-year
DLNV	=	total nonagricultural labor demand, laborer-year per year
EAPMV	=	proportion of migrant cohort that is economically active, economically active persons per migrant

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