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DEFINITION AND CLASSIFICATION OF "MODELS" AND POLICY ANALYSIS

A Self-Instructional Module for
Agricultural Planning Training Programs

Prepared for

PROPLAN

Interamerican Institute for Agricultural Sciences

San Jose, Costa Rica

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Introduction and Objectives

Policy analysis is defined as the process of creating and using information for policy decisionmaking, and models provide the necessary means for that creation and use of information. Models are particularly important as essential tools in the analysis and synthesis phase of the process but are also used in and influence other phases. This is true for policy analysis at whatever stage of agricultural planning -- formulation, implementation, control -- and for whatever area or areas of policy being analyzed.

This module presents a brief definition of this broad concept of "model" and a classification scheme for models. The learning objectives are that, after finishing this module, the trainee will be able to:

1. Define the term "model" and state how models contribute to policy analysis.
2. List the types of formal models and their characteristics.
3. Recall and define four out of five dimensions of classification of mathematical models.
4. Define disciplinary, subject matter, and problem-solving types of models and state their relationship to one another and to policy analysis.
5. Give examples of appropriate agricultural planning uses of various types of models, stating why they are appropriate.

Abstraction of Reality

It would be impossible for anyone to grasp the totality of a socioeconomic system in all its structural detail and complexity in order to diagnose the socioeconomic situation and analyze policy options to deal with it. Therefore, models are always, of necessity, used in policy analysis, where a model is defined as:

> A system which is an abstraction of another system, called the reference system.

A model, then, is an _____ of another system, which is called the _____ system.

Feedback: abstraction; reference

With this definition, the theoretical and operational frameworks of concepts which are the conceptual foundation of any process of data and analysis, are models of the socioeconomic system. That is, they serve as filters abstracting out only the essential elements for agricultural planning purposes, given the values reflected in the government's doctrinal position. For specific decision problems related to a particular policy area, however, even this conceptual model may be more complex and detailed than necessary to evaluate policy options. That is, the problem identification will have narrowed the scope to a particular problem or set of problems within the totality of agricultural planning. Based on the problem identification, then, a further abstraction takes place in modeling for the analysis and synthesis of policy options.

Define the term "model" in your own words.

_____

_____

_____

Classification Dimensions

The word "model" evokes different images in the minds of different people. For some, a model is a good-looking woman or man who wears new fashions in shows or magazine photos for advertising purposes. For others, a model is a plastic or wooden airplane or ship which comes in pieces and is put together by a child or aeronautical engineer. Still others see a model as a set of mathematical equations.

The general definition given above captures the essential element common to all these images: they are all abstractions of a reference system. The fashion model represents the potential consumer, the model airplane is a simplification of a real airplane, and the mathematical equations may capture the dynamics of a physical, biological or social process. However, the definition alone is not enough. The human mind seeks order and wonders whether these various models exhibit characteristics which can be used to classify them.

This section presents one such classification scheme (not necessarily the only feasible one) which is useful from a policy analysis perspective. Seven classification dimensions are defined and any given model may then be characterized by locating its position along each dimension.

Following the above definition of "model" as an abstraction of a reference system, give five examples of models encountered in your personal and/or professional life and state the reference system of each.

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Informal/Formal: Mathematical Models in Perspective

The form that a model takes can be classified as either informal or formal, as in Figure 1. For our purposes, informal models are mental models, that is, models which exist in the mind of the modeler/analyst. Such models tend to be vague, implicit, often subconscious images or concepts of how the world works. A decisionmaker who derives most or all of his information for decisionmaking from his own mental model is said, in colloquial English, to be making "seat-of-the-pants" or "intuitive" or "gut" decisions.

Formal models, on the other hand, exist in concrete, explicit form outside the modeler's mind. Thus, being explicit, they are available for critical scrutiny and evaluation and thus for conscious improvement and modification. There are four ways formal models can be further classified for policy analysis purposes: schematic models, physical models, role-playing models, and symbolic models.

Schematic models are diagrammatic or pictorial representations of the reference system. Thus, a road map is a schematic model of a city's road network or a nation's highway system, an architectural blueprint is a model of a residential or commercial building, and a political cartoon is a caricature of a public officeholder. Figure 2 shows schematic models of a supply-demand equilibrium and a hypothetical fertilizer yield response.

The fashion models and scale airplane models mentioned above are examples of physical models, as are wind-tunnel experiments, fertilizer trials on experimental plots, dolls and doll houses, and the statue of Cuauhtemoc in Mexico City. These are all physical models which approximate the actual physical form of their respective reference systems. Other

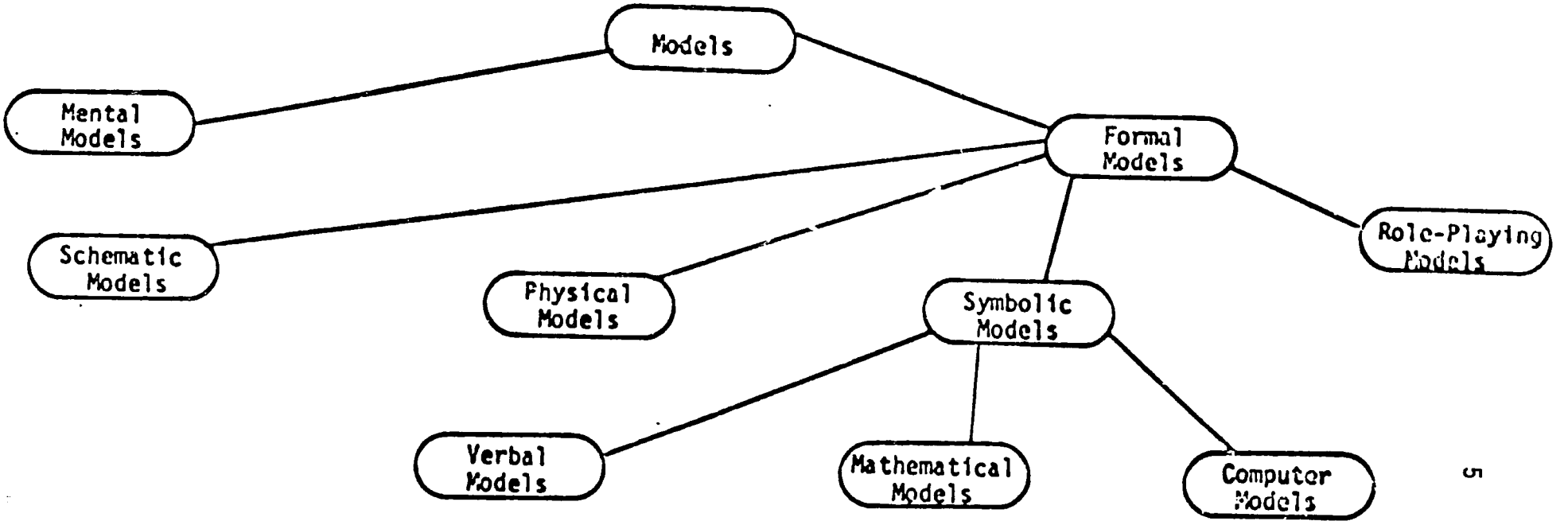
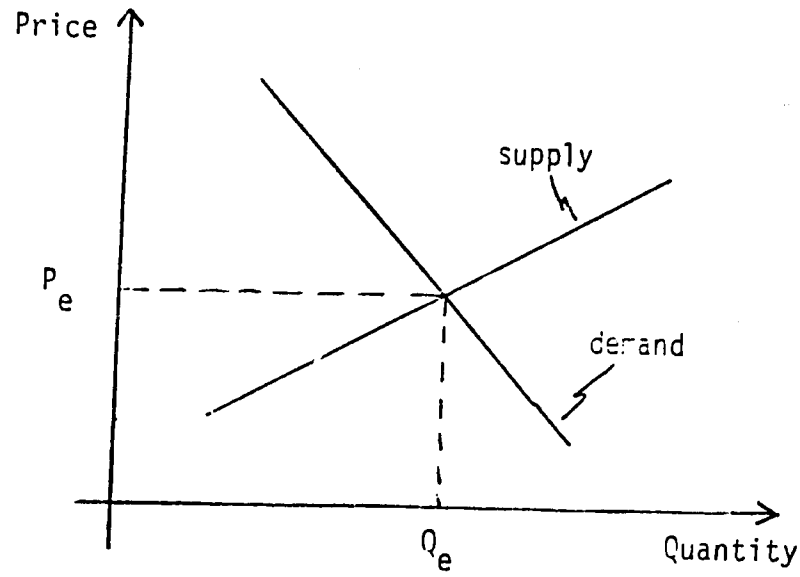
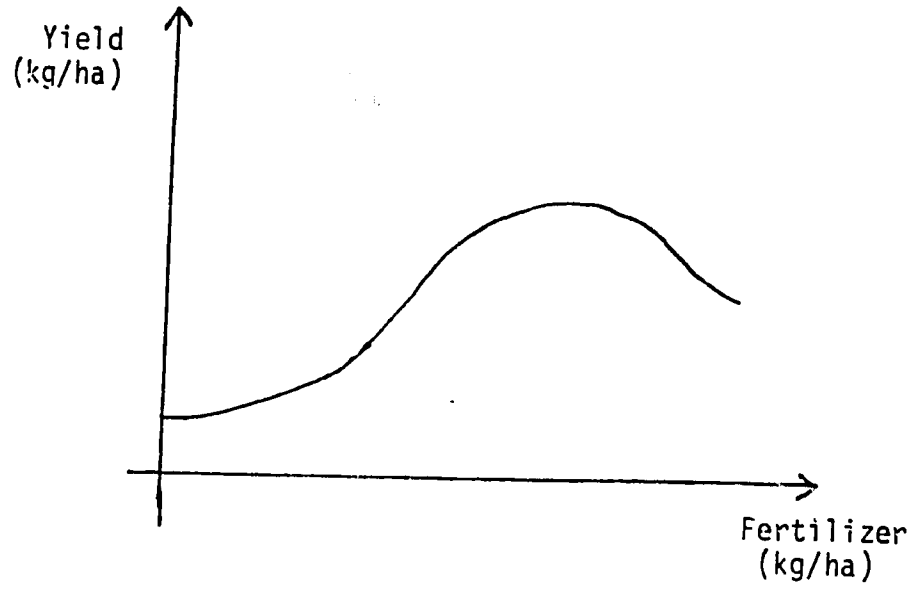


Figure 1. Classification of Models by Form

Source: Adapted from Martin Greenberger, et al., Models in the Policy Process, New York: Russell Sage Foundation, 1976.



(a)



(b)

Figure 2. Schematic Models of (a) Supply-Demand Equilibrium, and (b) Fertilizer Yield Response

physical models may look nothing like their reference systems, but are physical analogs which behave like them. Common examples are analog computers, which use electrical circuits, and hydraulic systems, which use water, tanks, pipes and valves, to represent the essential forces, flows and storages of physical or economic systems.

Role-playing models (or gaming simulations) provide a means of combining mental and formal models for policy analysis. Decisionmakers, analysts or experimental subjects are given 1) formal roles to play representing various participants in the reference system (public and private decisionmakers, affected parties, etc.); 2) a scenario describing the problem context in which to perform those roles; and 3) possibly a computer to assist in routine computations and bookkeeping. Everyday examples are theater actors in a play, children playing house with dolls, and the game of Monopoly, whose reference system is the real estate industry in Atlantic City, New Jersey, in the 1930s.

State which (if any) of the five examples you gave above are schematic, physical, or role-playing models.

_____

_____

_____

Give one or two additional examples each of schematic, physical, and role-playing models, stating the respective reference systems.

_____

_____

_____

Symbolic models use symbols related in a linguistic structure to represent essential elements and relationships of the reference system. Three classes of symbolic models can be identified, depending on the nature of the symbols being used: 1) verbal models, 2) mathematical models, and 3) computer models. Other types are conceivable, but these are the most relevant for policy analysis.

The symbols used in verbal models are words, and they are related by the syntactic structure of human languages. A recipe for example, is a verbal model of how to bake a cake or cook a stew.

Verbal models are very important in policy analysis because they provide the primary, direct link with the mental models of analysts and decisionmakers. This link is essential, because it is these mental models, no matter how extensively they are supplemented with complex formal (especially mathematical models, which are always used to provide the necessary judgemental and prescriptive information for making the ultimate decision.

Verbal models have some severe limitations, however, in policy analysis. Foremost among them is the fact that verbal models are frequently not unambiguous. Semantic problems arise from different interpretations (or connotations) placed not only on word-symbols but also on syntactic structures and vocal inflections. Furthermore, such models are difficult to manipulate and change and to replicate for repeated policy option experiments. Finally, a human language evolves from a particular cultural, social and historical heritage which places limits on the concepts that can be represented by the words and syntax of that language.

Many of these problems can be overcome by the use of mathematical models. The rules and symbols of mathematics are unambiguous, relatively

easily manipulable, and culturally neutral. Moreover, a much greater number of variables and complex interactions can be modeled mathematically than can be feasibly handled by verbal or mental models. A shortcoming of mathematical models, however, is that the language of mathematics is not as widely understood as other languages. As a consequence, substantial effort and care are required of analysts using such models to establish an effective communication link, verbally and/or diagramatically, between mathematical models and the mental models of decisionmakers and other analysts.

A common criticism of mathematical models is that they cannot incorporate many of the important variables and relationships which must be considered in decisionmaking but which cannot be quantified or precisely defined or for which data do not exist. There are several answers to this criticism.

First and foremost, mathematical models can never pretend to be the sole source of information for complex, socioeconomic decisionmaking. Other informal (i.e., mental) and formal models must always be used in combination with each other and with mathematical models in order to generate all the information needed to support decisionmaking. Nevertheless, mathematical models can increase the quality and quantity of a significant portion of the needed information over that which is attainable with mental or other less formal models. In this sense, quality is measured in terms of consistency and comprehensiveness, while quantity is increased by the ease of analyzing a greater number of more complex policy options.

Secondly, quantification is not necessarily a required feature of mathematical models. Indeed, the symbolic structure of a model--i.e, the variables included and their qualitative relationships to one another over

time--is frequently more useful as information than the quantitative data used in the model or generated by it. Therefore, nonquantifiable variables may be at least symbolically included in mathematicl models as long as their dependence and impacts on other variables can be defi If such definitions cannot be made, or even hypothesized, then their inclusion in other kinds of models, even mental models, must be precluded as well.

Furthermore, advances are being made in the art of mathematical modeling to facilitate the quantitative use of otherwise nonquantifiable variables. One example is the development of fuzzy set theory which establishes a means of quantifying so-called linguistic measures, such as "big," "adequate," "sufficient", "beautiful," etc.

Finally, it is frequetly said that mathematical models tend to require data which either do not exist or are hard to acquire in developing countries and which, even if they do exist, are often of poor reliability. Even for quantitative models, however, the quality of information generated by them is more critically dependent on structure (variables and relationships) than on data. That is, poor data with good structure yield more useful information than good data with poor structure.

Name at least three advantages and three disadvantages of mathematical models.

Advantages:

1. _____

2. _____

3. _____

Disadvantages:

1. _____

2. _____

3. _____

Feedback: Advantages--1) unambiguous, 2) relatively easily manipulable, 3) culturally neutral, 4) experiments replicable, 5) more variables and complex interactions can be included; Disadvantages--1) mathematics not a widely understood language, 2) many nonquantifiable yet important variables not included, 3) require data which may be poor or nonexistent.

While mathematical models can handle more complex structures more consistently than can verbal or mental models, there are, nevertheless, limits on the feasibility of finding general mathematical solutions without the aid of digital computers. Computer models, then, are the final category of symbolic model considered here. Using programming languages interpreted by computers as step-by-step instructions, computer models approximate mathematical models to calculate numerical solutions. Thus, computer models are models of models of models--abstractions of mathematical models, which are abstractions of verbal or mental models, which are abstractions of reality.

The remaining model classification dimensions discussed in this section apply to any type of model along the informal/formal dimension. That is, verbal models, schematic models, and mental models can also be located along a microscopic/macroscopic dimension and classified as static or dynamic, linear or nonlinear, etc. However, because of the importance of mathematical models and their potential contribution to improving the information generated by the policy analysis process, the focus of the discussion in the remainder of this module is on mathematical models.

Microscopic/Macroscopic

A model's abstraction of reality can be classified as microscopic or macroscopic. Actually, this dimension is a continuum. That is, there is no absolute category of microscopic or macroscopic. Rather, one model can only be said to be more or less micro or macro than another model, or to take a relatively micro or macro view of the world. Of course, the appropriate view to take should be dictated by the purposes of the model as specified in the problem identification.

Microscopic models tend to look at more detail, at individual entities or processes. Macroscopic models, on the other hand, tend to consider more aggregated processes and flows. For example, a population model that considered aggregate, annual average birth and death rates as functions, say, of average nutrition in the population would be more macro than a model which determined instances of births and deaths as they might occur at various points in time as functions of nutrition of individual persons. In turn, however, the former, more macro model, would be more micro than one which modeled population as a simple, exponential growth process.

Static/Dynamic

A model is dynamic if its behavior at any point in time depends on its behavior at earlier points in time, or equivalently if what happens now affects the future. If there are no intertemporal dependencies (time lags and rates of change), the model is static. For example, the yield response model in Figure 2b above is static, because yield at any time depends only on fertilizer application at that same time. However, if the model assumed yield also depended on accumulations of past applications, then it would be dynamic. In another example, a model which assumed crop land allocations in one year depended on prices in the previous years would be dynamic.

A grain storage model, then, would be classified as a _____ _____ model because the storage at any time is a result of past accumulations. A national income accounting equation is a _____ relationship because _____.

Feedback: dynamic; static because it merely adds up the components of income (either from production or from demand) in a given time period.

Deterministic/Stochastic

Uncertainty is a fact of life in decisionmaking, and models which explicitly consider uncertainty by incorporating random variables are called stochastic models. Otherwise, models which don't include random variables are deterministic models. In our yield response example, Figure 2 is a deterministic model, because, given the fertilizer application, we assume we know the yield. However, to consider possible weather effects, if yield were modeled as a random variable with an assumed probability

density function, perhaps with the mean of the distribution depending on fertilizer, this would be a stochastic model.

A stochastic model is one which uses _____ variables in order to explicitly incorporate _____ in the analysis.

Feedback: random; uncertainty

Whether a model should be stochastic or deterministic again depends on the problem identification. For short-term forecasting purposes, for example, the above yield model might need to consider randomness due to weather. For longer-term analysis of policy options, however, it may be sufficient to assume normal weather with the yield-fertilizer response taking on its average value over time, i.e. a deterministic model. On the other hand, depending on the purposes of the analysis, one may want a stochastic model even for long-run projections to consider, for example, uncertainties concerning the appearance of new crop varieties having an impact on yield.

In the case described below, what sort of model is applicable (stochastic or deterministic) and why?

It is desired to analyze the impact on the agricultural modernization program of a small, oil-importing developing country of international oil price instability. Experts can give estimates of minimum, maximum and most likely oil price trends.

_____

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_____

_____

Feedback: Stochastic if oil price volatility is expected and if the country will respond differently to fluctuating oil prices than to smooth, average trends (even if those trends are upward). Otherwise, deterministic analysis may be sufficient, possibly repeating it for each of the three (minimum, maximum, most likely) oil price assumptions.

Linear/Nonlinear

A linear model, or a linear system, is one which has the superposition property. Conversely, a nonlinear model does not have this property. Superposition means that, if a model responds in different ways to different stimuli, the response to the sum of the stimuli is the sum of the responses to the stimuli separately. This also implies that the response to a multiple of a stimulus is the same multiple of the response to the stimulus itself. Algebraically, superposition is expressed as follows:

For response y and stimulus x related in general by $y=f(x)$, if $y_1 = f(x_1)$ and $y_2 = f(x_2)$ for different stimuli x_1 and x_2, then $y_1 + y_2 = f(x_1) + f(x_2) = f(x_1 + x_2)$, and $ay = a\,f(x) = f(ax)$.

For example, if a proportional increase or decrease in fertilizer application, such as doubling it, causes the same proportional change in yield, i.e., doubling it, then the yield response is linear. Figure 2b represents a nonlinear yield response.

Frequently, it is possible to simplify a problem by approximating a nonlinear system by a linear model. This can be done if inputs (stimuli) to the model and the resulting outputs (responses) can be assumed to remain within a relevant range for which the actual behavior is close to linear. However, if there is a chance that inputs or outputs may be outside that range, such as bumping against constraints or with technological advance in long-run projections, the more general nonlinear behavior should be modeled. In general, however, nonlinearities do complicate models and significantly increase the difficulty of parameterizing and solving them.

Consider the following case and decide whether it represents a linear or nonlinear system and why.

The relationship between total expenditure on fertilizer and the quantity purchased, where the supplier offers volume discounts in which the price per kg decreases for larger quantities purchased.

_____

_____

_____

Feedback: Nonlinear because a given proportional increase in quantity purchased will result in a smaller proportional increase in expenditure.

Optimizing/Nonoptimizing

Optimizing models result in prescriptions for action. Specifically, values for a set of decision variables are determined in order to maximize or minimize a given objective subject to resource, technological, behavioral, logical and other constraints which may be specified. Optimizing models are used in policy analysis either to prescribe optimal policies for the political-administrative system or to describe the optimizing decision behavior of various components of the socioeconomic system (consumers, producers, households, etc.).

Conversely, nonoptimizing models do not seek to maximize or minimize anything. With such a model, alternative decisions (policy options) are assumed and the model executed repetitively to project the likely consequences of each assumption. These projections are then compared with one another by the analyst and/or the decisionmaker, and a decision may be made based on these comparisons, or additional options may be suggested for further analysis. In this way, the nonoptimizing model is combined with the decisionmaker's mental model to form a larger, optimizing model.

Optimizing models seek to _____

_____

while nonoptimizing models _____

_____

Feedback: determine a set of decision variables or policies which will maximize or minimize a given objective; project the likely consequences of each alternative decision or policy option.

The applicability of mathematical models themselves as optimizing models for prescriptive policy analysis is limited because of the difficulty of mathematically establishing the four preconditions for optimization. These conditions are:

1. Agreement on a decision rule, i.e., the objective function. In agricultural planning, there are typically a large number of objectives sought related to income, income distribution, political stability, nutrition, foreign trade, etc. Some of these objectives may not be readily quantifiable, and even if they are there is the problem of combining them in a single objective function, which introduces the second condition.

2. Existence of a normative common denominator enabling aggregation of the "goods" to be attained and the "bads" to be avoided. There may be conceptual difficulties in converting all agricultural planning objectives to units of money or utility in order to combine them in a single objective function, even if a weighting scheme (the first precondition) were agreed upon.

3. Existence of a normative common denominator which has interpersonal validity. That is, even if, for example, all "goods" and "bads" could be expressed in dollars (or pesos or bolivars or cruzeiros), is a dollar's worth of "goods" conferred on one segment of the population equivalent to the dollar's worth of "bads" which may consequently be imposed on another?

4. Establishment of second-order conditions. This is mathematical terminology for the obvious requirement that deviations from the optimum set of decisions should reduce the objective in the case of maximization problems and increase it in the case of minimization. This condition may not be assured in general--that is, at all points in time and throughout the relevant ranges of the decision variables--particularly if there are nonlinearities in the problem.

Name and describe in your own words each of the four preconditions for optimization. _____

_____

_____

_____

_____

_____

Disciplinary/Subject Matter/Problem-Solving

This dimension does not describe a system or mathematical property of a model but rather its domain of application with respect to policy analysis.

A disciplinary model is one based on the knowledge of one discipline, such as economics, physics, physiology, sociology, etc. Disciplinary knowledge embodied in models includes the selection of variables, the theories and hypotheses which structure those variables, and frequently types of data, data sources and modeling methodologies traditionally used in one particular discipline.

Disciplinary models contribute essential information to policy analysis. However, such models alone can rarely, if ever, be sufficient for decision-making. Socioeconomic planning requires information from many disciplines for sound decisions, thus disciplinary models cannot be called problem-solving models (see below). For example, partial and general equilibrium economic models are derived from the discipline of economics. While the information they can provide is necessary for agricultural planning, additional information from other disciplines (animal husbandry, agronomics, soil science, public administration, sociology, etc.), is also necessary.

A subject-matter model is one which can address a well-defined set of problems, where a problem is defined as a specific decisionmaking situation. For example, such agricultural policy areas as price and income policy, trade policy, etc., represent such sets of problems, called subjects. Of necessity, therefore, subject-matter models are multidisciplinary, using variables, theories, data and methodologies drawn from those disciplines having a bearing on the subject.

Subject-matter models, while closer to the needs of problem solving than disciplinary models, are not in general sufficient for problem solving either. A specific problem, i.e., decision to be made, may require information from more than one subject area. For example, a decision on an import tariff for, say, maize may require information on the impacts on consumer demand (a subject) and domestic maize production (another subject).

Problem-solving models, finally, are models used to solve, i.e., prescribe solutions for, specific problems. Being thus prescriptive, and given the preconditions for optimization discussed above, which essentially preclude the use of formal optimizing models alone for policy prescriptions, problem-solving models always include the informal, mental models of the decisionmakers themselves. Thus, they are combinations of formal and informal models from the disciplines and subjects having a bearing on the decision at hand.

Module Self-Test

1. Define the term "model" in your own words and briefly state how models are used in policy analysis.
2. List three types of formal models and give their characteristics.
3. List four dimensions along which mathematical models may be classified. Briefly describe the characteristics of each dimension.
4. Briefly discuss the distinction among disciplinary, problem-solving, and subject-matter models and their relationship to policy analysis.

5. For each of the following types of model, give an example of an agricultural development planning situation in which it may apppropriately be applied and state why it is appropriate for that case.

a. Verbal
b. Schematic
c. Mental
d. Mathematical
e. Microscopic
f. Dynamic
g. Optimizing