Part III. Systems Analysis and Simulation in Agricultural and Resource Economics
The initial draft of this paper was prepared at the University of California, Davis, for presentation at the annual AAEA meeting held in Gainesville, Florida, in 1972. The final draft was prepared in December 1974. In the interim the authors received support from the University of Missouri (Columbia) and Iowa State University. Perhaps the only advantage of permitting the drafting of this paper to continue so long was the opportunity that it provided for obtaining useful reviews. The original version of the paper and the survey chapters on econometrics and optimization, presented at the Florida AAEA meeting, were reviewed by Oscar Burt, Verner Hurt, and Richard Foote. Their comments were very useful in helping us to become more fully aware of some of the literature in agricultural economics. The reviewers appointed by the Literature Review Committee were Thomas Naylor, Ludwig Eisgruber, and Albert Halter. The comments by these individuals, particularly by Eisgruber, were helpful in forcing us to come to grips with the special features of systems analysis and simulation and the issues we have raised with respect to control. Our initial partners in crime, Richard Day and George Judge, should also be acknowledged for their helpful comments and suggestions. John Doll and Lee Martin, members of the Literature Review Committee, provided valuable comments on an earlier draft and at times not-so-gentle prodding concerning the final draft of the paper. Finally, a number of our colleagues were kind enough to comment on the manuscript (although their kindness did not always carry over into their review and comments), which also helped us to improve the final draft: Ben French, Gerald Dean, Bruce Dixon, John Freebairn, J. C. Headley, and Sam Logan. Errors of omission and commission are of course our own responsibility.

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Systems Analysis and Simulation:
A Survey of Applications in Agricultural and Resource Economics

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Systems analysis and simulation have had a recent but marked influence on teaching and research in agricultural economics. See, for example, the surveys by J. R. Anderson [1974a], Armstrong and Hepp [1970], and Charlton and Thompson [1970] and the expository treatments by Babb and French [1963], Dent and Anderson [1971], Eidman [1971], Eisgruber and Nielson [1963], Hesselbach and Eisgruber [1967], B. Johnson and Eisgruber [1969], Shruben [1968], Snyder and Swackhamer [1966], Sutter and Crom [1964], and Tyner and Tweeten [1968]. Surveys, expository treatments, and bibliographies on the subject outside of agricultural economics are numerous. Useful examples may be found in American Management Association Report 55 [1961], Harling [1958], Kotler and Schultz [1970], Malcolm [1960], Mihram [1972], Naylor [1969a, 1969b], Orcutt et al. [1961], and Vichnevetsky [1969]. Although most of the more formal concepts have been developed externally, the approach has found wide application in the profession.

The factors identified as accounting for the assimilation of systems concepts and simulation in agricultural economics and in other applied subject areas are of course about as numerous as the individuals who have commented on the subject (Cohen and Cyert [1965], Conway and Maxwell [1959], Hoggatt and Balderston [1963], Kornai [1971], Kotler and Schultz [1970], Kuehn [1962], McMillan and Gonzalez [1965], Martin [1968], Mesarovic, Macko, and Takahara [1970], Mize and Cox [1968], Naylor, Balintfy, et al. [1966], Optner [1960], Schmidt and Taylor [1970], Tocher [1963]). Three
factors particularly applicable to agricultural economics are the pragmatic orientation of the research, the increasingly eclectic nature of the problems studied, and the concern with the extension of knowledge and the related need for powerful pedagogical devices (Leontief [1971], Porter et al. [1966]).

Research efforts are usually designed to bring available information to bear on particular types of problems which arise in public and private sectors. The accepted mission of the profession is not so much to investigate theoretical or institutional subtleties as to provide a basis for informed decisions. If this admittedly oversimplified conception of the research efforts of agricultural economists is appropriate, then the problematic focus is useful in explaining the extent to which systems concepts and simulation techniques have been employed. It is in this situation that systems concepts and related techniques for analysis are most appealing.

Second, as problems for the agricultural sector of the economy have been redefined to include natural resources, community and economic development, more complex firm and market decision situations, and policy questions at regional and national levels, there has been an increase in the use of systems concepts and simulation. Models employed in studying these problems typically reveal unresolved theoretical questions. Moreover, the more ambitious of these models frequently cut across the boundaries of traditional disciplines. In such circumstances tractable models are likely to involve theoretical components in nonprimitive forms and even internal tests of alternative behavioral assumptions. To complicate matters further, these models do not usually lend themselves to a closed form solution. Results obtained through numerical and other analogs are therefore attractive alternatives.

Finally, there is the concern with transmitting research results to students, governmental officials, and agents in the industry serviced. Simulation methods have turned out to be an efficient means for communicating complex ideas and empirical results. This was noted and exploited rather quickly by agricultural economists (Babb [1964], Babb and Eisgruber [1966], Longworth [1969]). The advantages of the approach result from the comparative ease with which models, highly specialized to applied situations, can be described and from the possibility of allowing interactions between individuals and the models.

**Historical Perspective**

The history of research, teaching, and extension activities reveals a gravitation toward simulation methods and systems concepts. Historical observations of this type are useful since they give perspective to claims of novelty and a sense of proportion regarding results to be obtained from the "new" ap-
proaches. In viewing the development of that portion of agricultural economics which can be identified with model building, three periods are noted. Early efforts were empirical. Studies of farm management and industry organization were largely descriptive (Taylor [1929]). Hypotheses and models were suggested by observation and formed with few preconceptions suggested by deductive theory. Among the more frequently mentioned examples of this work are the studies by Black [1924], Bean [1929], and Moore [1914]. G. L. Johnson [1970] has referred to some of the methods involved in these studies as "pencil and paper" projections. Once formulated, these models were subjected to additional empirical information for evaluation and further refinement.

A second period of interest began in the late 1930s, and it was strongly influenced by parallel developments in economic and statistical theory. The neoclassical theory of consumer and firm behavior together with the theory of markets gave rise to a number of interesting and productive hypotheses and/or models for application in agriculture. The important departure brought on by these models was an increased preoccupation with the deductive basis for the hypotheses advanced. A chronicle of this sequence of events as it relates to applications of statistical method has been compiled by Judge [1968]. More attention was given to the process of model formulation. Specialization of the models for particular situations required statistical methods which explicitly recognized theoretical restrictions and problems posed by passively or nonexperimentally generated data. Finally, the importance of primitive behavioral assumptions in adding generality to hypotheses for statistical analysis was also recognized. Applications of models based upon these theoretical foundations seemed to represent the primary focus of the profession in the period following World War II.

More recently, interests have shifted to areas requiring models which depart from the rigidities of the neoclassical theories of firms, individuals, and markets. Related studies have raised perplexing methodological issues. The theoretical underpinnings of hypotheses (or restrictions) provided by the neoclassical theory have tended to become either unavailable or quite demanding in terms of deductive rigor. Choices open to the applied researcher are either to limit the scope of the investigations until more adequate theoretical results are forthcoming or to construct more descriptive models—incorporating the accumulated knowledge from economics and perhaps related disciplines where appropriate. In this sense the latter approach represents a combination of the early empirical methods and the more recent deductive methods (for example, Bonini [1963, 1964], Cohen and Cyert [1961], and Cyert and March [1963]).

Our introductory and historical comments have implied that simulation
and systems concepts have substantial potential for application in agricultural economics. The appeal of the approach is that it permits the investigator or teacher to view problems as they exist rather than as some predefined analytical structure admits. Implicit in this observation is the idea that flexibility is the major attribute of the systems approach. That is, the methods associated with the systems approach are commonly viewed as unconfining (Manetsch, Hayenga, et al. [1971]). We shall attempt to substantiate this claim in the review of past applied work. We shall also show that this flexibility comes at some sacrifice, apparently not fully recognized in agricultural economic studies. In fact, concern about these limitations is increasing. A general discussion of the limitations which may arise in connection with policy implications of agricultural sectoral models is presented by Rausser and Johnson [1975]. Similar criticisms have been advanced by the Department of Defense [1970] and more generally by Ansoff and Slevin [1968]. These shortcomings of the approach are suggested not to deter the use of systems concepts and simulation, but to provide a balanced survey. Alternative methods or approaches to applied problems can be viewed as incurring opportunity costs for the usefulness of anticipated results. It is our intention to develop the survey so that these alternatives are apparent.

Our objective is to provide a heuristic survey of the postwar developments in simulation and systems analysis within agricultural economics. In this context it is important not only to summarize applications but also to provide a systematic basis for evaluating these efforts. The first portion of this chapter is devoted to providing the systematic basis. Following this, applications of systems concepts are examined by functional categories. These include gaming, process models, firm models, market models, aggregate models, economic development, and natural resource models. Although the classification is arbitrary it provides a convenient framework for comparing and evaluating the studies reviewed. The survey concludes with a critical appraisal of agricultural economics work involving systems and simulation. This critique includes an assessment of noteworthy findings, promising developments, and conceptual issues which have been raised by the application of systems and simulation methods.

Since the evaluation of empirical results presented in the reviewed studies is the subject of other survey papers commissioned by the American Agricultural Economics Association, our comments on these aspects are limited. Instead our principal concern is with model characteristics and with the application of simulation methods.

Nomenclature

A number of terms common to systems concepts and simulation have special-
ized meanings. It is important therefore to identify these terms before the discussion of the approach and/or methods. Many of these definitions are consistent with treatments existing in literature but are included for completeness. Where possible, consistencies and departures from definitional frameworks usually found in the literature are indicated.

A "system" is a collection of interrelated components or elements with a purpose. More elaborate definitions of systems featuring specifications of the number of elements, the types of relationships between elements, and purposes or goals are common (Ackoff [1971], Mihram [1972]). These features will be explicitly recognized in the section on the classifications of systems types. For the present it is noted that an interesting discussion of model purpose and type as related to agricultural economics has been provided by Drynan [1973].

A "model" is a synthetic representation of a system. Models of systems may take a variety of forms. Four of these which have common usage in systems studies are discussed by Ackoff [1971], Churchman [1971], A. M. Lee [1970], and Mihram [1972]: symbolic models (those which require mathematical or logical operations and which can be used to formulate a solution to the problem at hand); iconic models (those which pictorially or visually represent certain aspects of a system); analog models (those which employ one set of properties to represent another set of properties of the system); and physical models (those which involve material objects in representing systems). For the purposes at hand attention is confined to symbolic and analog models. The bulk of modeling in agricultural economics has involved symbolic representations of systems, and digital or electric analogs of such symbolic models or systems. That is, because of the predisposition of agricultural economists toward abstraction, studies of systems normally proceed with the development of a symbolic model. Symbolic models are then typically converted to digital or electric analogs for purposes of investigation.

Constructing a model of a system may be viewed as a development process. Activities occurring in this developmental process have been identified as analysis, synthesis, and design. "Systems analysis" is the purposeful study of systems. "Systems synthesis" is the act of characterizing a system, including the identification, classification, and specification of components or elements and the relationships giving the model a cohesive structure. "Systems design" is the process of investigating and selecting modes for studying systems (that is, selecting the framework within which regulatory, structural, and institutional changes of systems are to be examined). Alternatively, design can be viewed as the process of choosing a format for combining the synthesized system components and relationships to meet modeling objectives.

Analysis, synthesis, and, for most problems, design may be viewed collec-
tively as steps in the process of developing a sufficient understanding of a system for the construction of a model. Hence, these activities may be interpreted as steps essential to scientific inquiry. Isolating primitive elements and concepts or relationships and weaving them into a representation of the system which is consistent with its perceived purposeful functioning and the research objectives is the essence of these modeling activities.

“Experimentation” is the purposeful perturbation of the system or model representation and observation of the results. In our use of this term we are obviously after a very general concept of the process associated with the manipulation of systems or models and observing consequences. The generality of the definition is useful since it permits the consideration of simulation, Monte Carlo methods, and gaming as special types of experiments. In addition to providing a framework for considering the alternative process of experimentation, the approach is convenient for the subsequent discussion of experimental design.

“Simulation” is a process of experimenting with models or systems. It is important to note that this definition implies a view of simulation as a method and not as a substitute for a model (Naylor [1971]). Building a representation or model of a system could be viewed as constructing an image or simulation of the system. According to the definitional structure adopted for the survey, this process is termed “model construction” and experimentation with it is termed “simulation.” There may be some confusion in this choice of terminology since simulation is used with both meanings in the systems literature. For our purposes, a simulation is an experiment with a model of a system, not the model itself. Given this definition, there are three useful but not necessarily exclusive distinctions which can be made for types of experiments with systems models. (For a more detailed discussion of these alternatives for analysis of systems models, see Rausser and Johnson [1975]. The more refined classification used in the paper cited includes analytical closed-form representations, analytical simulation, and ad hoc simulation.)

“Simulation algorithms” are techniques for characterizing the operations of systems models through related constructs. “Analytical simulation” is a method of experiment based on systematized rules of search and design. “Exploratory simulation” is a process of monitoring outcomes with systems which are not algorithms and which do not involve systematized rules of search and design.

For purposes of the survey we confine our attention to analytical simulation and exploratory simulation. Simulation algorithms were included simply for completeness and to give some substance to the earlier conjecture that many of our so-called modern concepts in the study of systems can be viewed as outgrowths or extensions of ideas which have long been familiar in prob-
lem solving. This observation is more fully developed by Day and Sparling [1977]. Iterative procedures incorporated in algorithms of the type used in solving optimization problems may be viewed as sequences of simulations of the digital counterpart of an algebraic model (Dorfman [1963], Meier [1967]).

Much is made of the distinction between analytical and exploratory (or ad hoc) simulation methods. Analytical simulations as indicated by Dorfman [1965] have distinct advantages in studying characteristics of more tightly defined systems models. Exploratory simulations are, however, quite useful in certain phases in model construction and evaluation.

The relationship between computer simulation, Monte Carlo methods, and gaming is illustrated by the following definitions. A “computer simulation” is an experiment with a digital or electric analog of a systems model. The “Monte Carlo method” is a branch of mathematics which is concerned with experiments on sequences of random numbers (Hammersley and Handscomb [1964]). This definition of Monte Carlo methods is somewhat more restrictive than modern usage of the term might suggest (J. R. Anderson [1974a], Donaldson and Webster [1968], A. M. Lee [1970]). Broader definitions of the Monte Carlo method encompass most numerical techniques, whether employed in stochastic or nonstochastic models. The essential element in most definitions seems to be that the Monte Carlo method refers to experiments with algebraic models which involve a stochastic structure. If this definition is adopted, then Monte Carlo methods are most closely related to simulations with algebraic models which involve a stochastic structure. If this definition is adopted, then Monte Carlo methods are most closely related to simulations with algebraic models which involve a stochastic structure. If this definition is adopted, then Monte Carlo methods are most closely related to simulations as employed with closed form stochastic models (J. R. Anderson [1974a]). In fact, given our definitional structure, Monte Carlo methods are a proper subset of simulation methods. This follows because Monte Carlo methods refer to experiments with special types of systems models. However, the term is useful even in the discussion of systems and simulation since by convention it refers to a substantial body of numerical work in statistics and mathematics.

“Gaming” is the process of experimenting with models of systems which involve a human response as a strategic component. As the definition implies, games as models of systems are partially physical. They are models involving controlled human interactions. Experiments with such models are usually termed “gaming.” These experiments are often highly structured in terms of participant options and possible interactions (Evans, Wallace, and Sutherland [1967]). As with the Monte Carlo methods, gaming methods are therefore special types of simulations, again with the specialty coming from the types of models and/or systems involved in the experiments.

**Systems Concepts**

In addition to the fundamental definitions in the preceding section, the sys-
tems literature includes a number of concepts which must be clearly identified if the survey of applications is to be internally consistent. The informal nature of the models used in applications of systems and simulation in agricultural economics makes the commonality provided by this discussion of concepts important as a basis for cataloguing applied studies and thus providing systematic content.

Types of Systems

There are numerous approaches to the classification of systems (Ackoff [1971], McMillan and Gonzalez [1965]). As might be expected, the existing approaches including the one employed for the purposes of this survey are based on types of components, relations, and system purposes. More refined and specialized classifications based on economic considerations have also been advanced (Naylor [1971]). System and model types identified here, however, are confined to those required in structuring the survey.

Stochastic/nonstochastic systems. Stochastic systems include random components or relations. The converse is true for nonstochastic systems. A similar partitioning is useful in distinguishing between systems models. The distinction implies that it is not necessary for the stochastic characteristics of the model to correspond to those of the system. Stochastic models of nonstochastic systems are, for example, quite consistent with the Bayesian view of probability theory (Jeffreys [1961]). From a pragmatic standpoint the relationship between models and systems can be rationalized on the basis of model purpose. For example, useful models for decision purposes are generally simplified representations of systems; as such, the more intricate aspects of the systems outcomes may be characterized using error terms with prescribed probabilistic characteristics.

Static/dynamic models. The distinction refers of course to the time dimension of the system or model. Static models abstract from time while dynamic models are ones in which time enters in an integral way (Frisch [1935-36], Samuelson [1947]). Again, a correspondence between model and system with respect to this characteristic is not necessary. To illustrate the point we simply note that many agricultural economists for a number of years have been busily applying static neoclassical theory to intrinsically dynamic systems.

Dynamic systems and their representations often incorporate a concept termed "feedback." The term, although used in a number of contexts, refers to information flows between time periods in dynamic models. In fact, it is essential to models which are truly sequential in nature. For this reason, attempts to develop provisions for feedback in models of systems have attracted substantial attention (Forrester [1961], Nance [1971]). In the context
of model construction, feedback is most naturally viewed in terms of control.

**Open/closed systems and models.** Closed systems and models are bounded in terms of their relationship to the environment. If environmental factors modify the system or model in a relevant way, then the system or model is said to be unbounded or open (Mihram [1972]). Clearly the closedness or openness of a system or model is related to the boundedness of the elements. Obviously, boundedness is dependent upon model and system purpose. Most models surveyed, because of the economists' concern for analytical content, are bounded. However, in the sense that such models are used in evolving an understanding of the system and, accordingly, modifying the structure, they are open.

**Historical/nonhistorical distinctions.** These terms are used with two meanings in the systems and simulation literature. In the early writings models were constructed with the objective of reproducing historical sequences of events (Forrester [1961]). Examples of these historical models may be found in early behavioral studies of the firm (Cohen and Cyert [1965]), Shubik [1960]). The distinction between historical and nonhistorical models in this early literature was with respect to whether or not recorded values of environmental elements were characterized by estimated probability distributions or as observed sequences (Churchman [1960]). More recently the terms have been used to distinguish between concepts of systems and systems models which are temporally related and those which are not.

**Decomposability.** The concept of decomposability has been widely employed in agricultural economics applications. Decompositions of aggregate models into sectors (Manetsch, Hayenga, et al. [1971]) and firms by function (Babb [1964]) are examples of situations in which the concept has been applied. An important advantage of this view of systems and models is that it permits the development of research projects in manageable parts (French [1974]). When systems and models are decomposed, the feedback concept again assumes importance. In this instance it refers to flows of information between the decomposed parts of the system or model.

**Interaction.** Systems concepts can embrace entities which are extremely complex. In such situations researchers may begin with highly simplified models and develop them on the basis of interactions with the system. That is, the modeling process is one in which information on the system, obtained by viewing it in the context of a model, is used in refining provisional specifications. For example, models of complex systems may be initially specified using functional components, with the interconnections represented in a highly simplistic form. Information obtained by simulating the model may then be used to develop more realistic relationships between the components and, in fact, to specialize component specifications. This information may result
from comparing the outcomes of the simulations to the observed system or from more implicit comparisons of outcomes with preconceived ideas about the working of the system.

Models which explicitly recognize this process and structure the relationship between researcher and system may be termed interactive. The consequences of these characteristics are far-reaching and involve the so-called "uncertainty principle of modeling" (J. R. Anderson [1974a]) and, more generally, adaptive systems models and various learning hypotheses. With each of the alternatives the modeling of systems is viewed as an exploratory process. We begin with a modeling objective but substantial uncertainty about the structure and functioning of the system. A trial and error approach is used to isolate the important elements of the system and their implications for the model formulation. Whether this evolutionary process is itself modeled as an adaptive or dual control problem or proceeds in a more ad hoc manner, the end result is most likely a model characterizing more accurately those system aspects that are critical to the purpose of the modeling exercise.

System purpose. This characteristic of systems and models can be tied directly to the more traditional concepts in agricultural economics. Our characterization of systems by purpose will permit classifications for the applications survey along established lines of inquiry. That is, economic aspects of agricultural sectors may be viewed as having general purposeful functions in terms of production, distribution, and valuation, depending upon the paradigm through which the system is perceived. Refinements associated with identifying more operational concepts of purpose have to some extent led to a compartmentalization of the systems research. That is, we find studies of the processing system, firm growth, and development each referring to a purposeful function of the system. The identification of systems functions and modeling objectives is thus crucial to the evaluation of the systems research surveyed and more generally to the evaluation of the systems approach.

Modeling Objectives

Models are constructed to provide information about systems. Hence, they may be used for a number of purposes not necessarily corresponding to the purposeful functioning of the system. Depending upon research objectives, the investigator may use descriptive, explanatory, predictive, or decision models.

Descriptive models. Most descriptive models are exploratory in nature. The researcher observes a system and constructs a model which is designed to describe the functioning of the system. That is, "a descriptive model simply sets forth a set of relationships which have 'bound together' different variables in situations in which they have been previously observed." (Strotz and Wold
Information developed from the model is then used in attempts to understand the functioning of the system and to support inferences under alternative assumptions about conditioning by the environmental factors.

Descriptive models have been widely employed in systems studies. Clarkson and Simon [1960], Cohen and Cyert [1965], Forrester [1961], Goldberg [1968], Orcutt [1960], and Shubik [1960] are among those who have advocated and developed descriptive modeling techniques. As the cited works suggest, the emergence and prominence of descriptive modeling is closely tied to behavioral theories in the social sciences. More recent descriptive models attracting substantial attention were employed by Forrester [1971] and Meadows et al. [1972] in investigating implications of a long-term continuation of assumed relationships between population, resource consumption, and the societal and economic structure.

Explanatory models. Models of this type are constructed with objectives which are in a number of respects similar to those for the descriptive case. The principal distinction is that explanatory models are causal. This is of course a "loaded" term and hence may require elaboration. In this context we are using the definition of Strotz and Wold [1960]. That is, in the statistical sense "z is a cause of y if, by hypothesis, it is or 'would be' possible by controlling z indirectly to control y, at least stochastically."

The relationships specified involve assumptions about the direction of influence of variables. Hence, in explanatory models the chief concern is with the isolation and refinement of causal relationships and tests of associated implications vis-à-vis the observed system and a priori theories. Internal consistency and tests of competing hypotheses on the behavioral mechanism driving the system are the objectives emphasized in these modeling endeavors.

Prediction. Forecasting and prediction are important functions of modeling efforts in agricultural economics and other policy sciences. Predictions of price movements, changes in location, mobility of factors, and the like have an important role in many policy questions. In these models there can be less concern with internal workings than with forecasting accurately. This is particularly true of situations in which the dynamic models are constructed to deal with short-run forecasting problems (Gross and Ray [1965]). From a philosophical standpoint these models are often advanced in a positive economics tradition. As will be apparent from the subsequent discussion, the predictive objective of the modeling activities admits some different procedures for model construction and simulation.

Decision problems. In economic systems these problems have a generally accepted set of components. As usually conceived, they involve controllable and environmental variables, objective functions, and structures which relate the controlled and environmental variables to output variables (Fox, Sen-
The model specified as an optimizing problem is used as a basis for policy prescriptions for the system. As a consequence research efforts are concerned with both the implications of the optimizing solutions and the accuracy with which the model portrays the system. When expressed in a dynamic context, these two problems can be productively viewed in adaptive or dual control theory frameworks (Rausser and Freebairn [1974a], Tse [1974]).

Decision problems may be usefully grouped into two major types—regulatory and institutional. Regulatory decision models are developed for policy questions given a particular institutional and environmental structure (Haitovsky and Wallace [1972]). For institutional decision models, the structure itself is allowed to vary and thus the larger questions on the organization of the general system within which the subsystems operate are considered. Such decision problems are of course most difficult, since by convention the subsystems of study have usually been examined within the context of dominant paradigms. The systems approach to construction of symbolic and digital models has made a substantial contribution by creating an awareness of the limitations of research results based entirely on regulatory models of systems.

**Paradigms.** Since the publication of Kuhn's work [1970] concerning scientific revolutions, our perspective on the modeling of systems and the implications drawn from related research results has changed. The major point made by Kuhn was his observation on the importance of the paradigm concept to the results of scientific investigations. Roughly put, paradigms are to scientific inquiry as maintained hypotheses are to the standard types of statistical investigations (Rausser [1973]). In other words, the philosophical structure within which we operate contains a number of propositions or primitive concepts which are not, in principle, testable. While this is somewhat disquieting for the more traditional philosophical framework (Black [1953], Popper [1959]), recognition of the existence of paradigms has substantial implications for the analysis of systems. The departure from standard neoclassical models represented by systems research efforts, if generously interpreted, may be viewed as the beginnings of a professional movement to paradigms more appropriate for current policy questions. In fact, a chronicle of the evolution of the ideas on models and systems as viewed in terms of a departure from the neoclassic economic theories since the early 1960s might be appropriately titled "paradigm lost."

**Systems Analysis**

As suggested earlier, systems analysis is the process by which an investigator with a specific objective initiates modeling or research. The system in
question is observed and the investigator's perception of the problem under investigation is sharpened. It is conventional to view this process as one in which the elements and components of the systems are identified and the relationships between them are specified. Decisions made in this phase of the research process relate to the size and scope of the model, the level of abstraction appropriate for question under study, and the sources of information and data. Most of the systems studies by agricultural economists have (1) a body of relevant theoretical and applied (disciplinary) literature (2) operating data on some or all of the variables or elements identified as possible components, and (3) a stock of informal knowledge distilled by individuals closely connected or involved with the operation of the system.

Systems analysis is the process of accumulating this information along with the observed behavior of the system and coming to an initial decision as to research strategy (Deutsch [1969]). The diversity and specialty of methods and models available in the systems literature make the process more involved than if traditional economics paradigms were employed. The preliminary difficulty in the selection of an appropriate approach at least admits the advantage of not operating with an overly confining model or paradigm. For this reason the systems analysts may find their efforts more innovative in nature than those of researchers following a structured approach or existing paradigm to the problem under investigation.

Systems Synthesis

After studying the system and accumulating the associated data and results as well as decisions on a research strategy, the investigator is confronted with the problem of developing an analytically tractable characterization of the processes to be investigated. Activities of identifying and classifying elements and components by function, specifying the environmental consideration and alternative institutional frameworks, and distilling the behavioral hypotheses are all involved in systems synthesis. This is the juncture at which the investigator's perception of system and modeling objectives must be formalized.

A major advantage of identifying this stage of the systems approach is that it permits attention to be focused on the process of distilling accumulated knowledge into a manageable set of perceptions. The comparatively unconfining approach to synthesis which is typical in systems work gives rise to the possibility of developing models which are more specialized than those which result from more structured approaches. An advantage of these specialized models for the accumulation of scientific knowledge is their potential as sources of behavioral hypotheses which can be refined and studied in more simplified constructs.
The concern with firm growth represents a particularly interesting example of systems synthesis in agricultural economics research. As growth phenomena began to attract attention among researchers, systems models were synthesized as a basis for refining the problem and the hypotheses to be investigated. Results of this work have subsequently been incorporated in more formalized analytical models of dynamic firm behavior. That is, the evolution from highly personalized and specialized models to ones which involve more analytically tractable structures and results of less specific applicability is easily traced in this area of inquiry.

The systems literature contains numerous suggestions on mechanical aids for the synthesis process. Event graphs, tree diagrams, and flow charts are among the aids mentioned as possibilities for structuring systems synthesis. Whatever the symbolic approach, it is important to recognize that at this stage the major components of the systems model emerge and are linked to the modeling objectives and the system in question.

**Systems Design**

Designs of the systems and, in fact, of the models themselves are important since they determine the nature of questions to be asked in the inquiry. At this point research objectives and the elements of the model are structured for the analysis of regulatory decision alternatives. That is, the institutional framework within which the model is to be studied is set forth and incorporated in the structure. If viewed from a more general vantage point, the systems design problem is one of selecting hypotheses associated with the system which will have a maintained status in the study of the model. These decisions, of course, depend on the purpose of the system and model, since they set the framework within which the regulatory questions concerning the system are to be posed. Appropriate designs are thus crucial in positioning the model to produce information on the system which is consistent with the objectives of the investigator.

Depending on the objectives of the model, the design may be a hypothesis on the working of the system, the structure of a decision model or a particular forecasting mechanism. In this regard it is important to distinguish between the more utilitarian design problems within the model (regulatory questions) and those which involve maintained hypotheses on the function of the system (institutional questions). The latter are in a real sense investigator control variables in the implicit optimization problems associated with developing suitable descriptive, explanatory, and forecasting models. As decisions taken in regard to design determine an institutional framework, they also constrain regulatory results obtained from systems models.
Model Representation

Models of systems tend to take highly variable forms or structures, even when the purposeful functioning of the system and the modeling objectives are the same. Nevertheless, modeling processes and the considerations influencing them are fairly standard. In this section these processes and considerations are reviewed, emphasizing their adaptive and sequential nature.

Classes of Models

The earlier discussion of systems types applies as well to models. That is, models are themselves systems. The nonstochastic/stochastic classification is most important in regard to the development of model representations. Following an approach suggested by Bellman [1961] and independently by Fel'dbaum [1965], we can distinguish three types of models in relation to this characteristic: deterministic, stochastic, and adaptive.

Deterministic models are those with all components and relationships assumed known with probability one. Stochastic models are those with some random components and relationships but with the distributions of the associated random variables assumed to be known. Adaptive models are those with components and relationships about which there is initially some uncertainty (for example, the parameters of the relevant probability distributions may be unknown). The uncertainty on the structure and components changes by learning as the process evolves. Clearly, then, the first two model types are special cases of adaptive models.

Adaptive modeling can incorporate learning processes which are passive or active. Passive learning processes are those in which information is accumulated about the system or model strictly as a by-product of operating or controlling it. Active learning processes are those in which the learning and the operation of the system are treated as joint products; this feature may be referred to as dual or adaptive control. Active learning processes, although not formalized or structured, are obviously common in systems modeling. That is, provisional models are constructed and then probed or simulated as a basis for improving the representation as well as for obtaining the information to satisfy the modeling objectives.

The structure of the problem associated with developing model representations which best meet the research objectives and thereby provide the most accurate representation of the system (given restrictions on resources and model purpose) is one of adaptive control. To be sure, strategies for developing adaptive models may be viewed as solution sequences for control problems. This aspect of the model construction process is emphasized in the subsequent discussion since it represents a unifying concept for connecting the
various tasks involved in developing representations of systems. Much of the perceived flexibility of systems modeling and simulation as approaches to agricultural economics research problems derives from the use of an unstructured adaptive modeling process. By emphasizing the features of the adaptive control process involved in model construction our comments will illustrate the price of this flexibility in terms of inefficient model development.

Construction of Models

Model construction can be viewed as involving five principal steps. These steps are model specification, parameter estimation, verification, validation, and revision. At each of the steps the researcher must make decisions which are crucial to the success of the modeling endeavor. Although steps taken in the process of constructing models are reversible, it is important to recognize their opportunity costs for inefficient strategies with respect to these five steps along with implicit time and resource budgets.

Specification. After the system has been analyzed and a model has been synthesized and designed, the investigator is confronted with the specific problems of model specification. For digital and symbolic models this specification, whether provisional or final, must include an algebraic structure and an operating model. Such specifications, of course, involve compromises. If the models are specified on the basis of primitive and generally accepted normative and physical concepts, the results have wider acceptability. Structures deduced upon accepted normative propositions and established technical relationships have greater generality, given that the paradigm governing the modeling process is appropriate. Models of this type are more easily tested and usually are less complex structurally. Alternatively, there are highly specialized models based largely on ad hoc propositions. In contrast to the primitive alternatives these are more easily specified because the process is one of simply observing the system and formulating (in abstract form) the behavioral and other structural relations. The difficulty with these models relates to the information content of the results. If the behavioral and structural hypotheses are not refined, then empirical tests are reduced in importance by virtue of the large number of competing hypotheses. There are obviously trade-offs; primitive models are less complex structurally and allow formal tests to be developed but are difficult to specify without artificially restricting the investigator's perception of the system. The converse holds for specialized models.

The process of model formulation for investigating economic systems therefore imposes some fairly artistic demands upon the researcher. Often we find model specification proceeding in the aforementioned adaptive fashion—typically tending toward some middle ground. Models with high empirical
content are refined so as to adapt them to larger classes of systems. Alternatively, models more influenced by theory tend to move toward greater realistic content, becoming specialized to particular situations.

Parameter estimation. Parameters may be estimated using a number of methods. These range from econometric methods applied to linear simultaneous equation systems (Hood and Koopmans [1953]) to those which tend to disregard sample or past observations on the systems (Forrester [1961]). In the former situation a maintained hypothesis is specified and sample information is utilized to obtain estimates of the structural parameters and sampling distributions. In the latter approach Forrester rejects available sample data as containing little or incorrect information about the structure. Parameter estimates are introduced on a subjective basis or are calculated using technical and engineering types of relationships (Marsden, Pingry, and Whinston [1974]). Hence, systems models may rely heavily upon statistical method or may reject the use of available historical data (1) because it is inappropriate (Forrester [1968]), (2) because it involves substantial error (due to the sampling process), or (3) because structural change is suspected.

In addition to differences due to assumed sources of useful information, parameter estimation methods are frequently sequential or iterative in nature (Wallace and Ashar [1972]). It is also common for the estimation process to involve considerable pretesting of the structure. Formal statistical procedures have been developed for such problems. They are reviewed by Judge [1977] (in particular see his discussion of preliminary test estimators).

Thus, parameter estimates are obtained using sample or prior information and then modified based on performance of the model representation for the system. Because of the diversity of estimation methods both in terms of information sources and the iterative procedures involved, a rather general framework is needed for evaluating applications of the systems concepts and simulation in agriculture. Such a framework is available and, although impractical for many applications, it does give some perspective for the work to date. This perspective can provide a basis for assessing the advantages and limitations of the past work and can furnish some insight on possible future developments.

A framework for considering estimation in systems models must of course reconcile the use of alternative data sources. Appropriate approaches include Bayesian (Zellner [1971], Zellner and Chetty [1965]) or classical mixed estimation methods (Aitchison and Silvey [1958], Judge and Yancey [1969], Theil [1971]). In both instances sample data and extraneous information on parameter distributions are systematically applied to obtain estimates of the structure. Recent advances in mixed and Bayesian estimation techniques also admit evolving structures with nonstationary parameters (Eldor and Koppel
In each of these approaches data and non-data oriented processes are essentially the same with the difference being a matter of the relative certainty with which the extraneous estimates of the parameters are held.

In addition to their appeal for the data source problem, the Bayesian and mixed estimation approaches are sufficiently general to provide for the incorporation of iterative procedures frequently used in obtaining parameters of systems models. Given the selection of a particular model or representation on the basis of available data or information, classical inference procedures are violated if the same information is reused to estimate the parameters and investigate their reliability. In many applied situations such inconsistencies are either not recognized or are justified on grounds of simplicity, avoidance of complications, and the substantial uncertainty associated with selecting the proper maintained hypothesis or model specification—the last typically a result of the model specification alternatives mentioned earlier (Rausser and Johnson [1975]).

In the context of these difficulties the Bayesian approach at present seems to be the most viable one for selecting among alternative model specifications. The difficulty in making applications of it concerns the problem of isolating a structure sufficiently general that choices of alternative forms can be considered as nested hypotheses. In fact, Dhrymes et al. [1972] have recently suggested that, given the availability of informative prior distributions, the Bayesian approach to the model selection problem offers a far handier solution than the classical approach. Leamer [1970] has explored the implications of alternative weighting functions in this context, and Zellner [1971] has provided a general outline of Bayesian procedures for comparing and choosing among models. A useful summary and comparison of Bayesian and classical procedures for discriminating among alternative specifications of single-equation models has been presented by Gaver and Geisel [1974]. This treatment includes some promising classical developments as alternatives to the currently more popular Bayesian views on the discrimination problem.

Parameter estimation is also influenced if models are adaptive. Many times while systems models are being constructed, estimated, and simulated additional data on the structure becomes available or is actively sought. Although systematized procedures for handling the estimation problem in such models currently involve mathematical difficulties, applied systems modeling appears to be gravitating in this direction. Results which may be of some use in grasping these ideas are contained in Aoki [1975], Chow [1975], Prescott [1972], Rausser and Freebairn [1974a], Tse [1974], and Zellner [1971].

Verification. This is the process by which the investigator determines whether or not the model performs in accordance with the intended purpose.
For example, in algebraic models, verification is concerned with completeness, the existence of solutions, internal functioning, and the like. The most common use of the term, however, appears in conjunction with digital computer models or analogs. In this context the term relates to establishment of desired isomorphic relationships between system, model, and digital analog.

Validation. This represents the process of corroborating the model with the system. In the construction process validation is employed to evaluate the ability of the model to duplicate the required characteristics of the system and in fulfilling the modeling objectives. The process is clearly a judgmental question and as such presents a number of problems (Naylor and Finger [1967]). First, if the requirement is a close corroboration with the system, how should the data on the functioning of the system be summarized and compared to outputs of the model for tests of consistency? Second, how important is prior information relative to the data on the system and how should these two types of information be combined in corroborating the model?

At a more philosophical level, what framework should be employed to determine which hypotheses on the system are to be tested and which are to be maintained? The paradigm within which we operate also renders a number of questions unanswerable. Simulation and analytical methods are to an extent competing alternatives in the process. The basis for a choice between these alternatives is examined later.

Revision. The four preceding steps may be considered to be either a final process or a provisional process. In a provisional process the fifth or revision step is concerned with an assessment of whether or not the model should be altered to make it more suitable for the intended objectives. Information on which this decision is based may come from observing the system, on the basis of the implications of model outputs, a refinement of modeling objectives, or a refinement in the model.

Whatever revisions are made, it is important to specify systematically the sources of information and the process by which the information is to be used to revise the model. Such conditions are as much a part of the prior information used to construct the model as the more frequently employed theoretical underpinnings and data sources. If such specifications are not included, then the modeling process becomes identified with the investigator or the team involved in its construction. Its value for other research efforts or general scientific purposes is therefore severely limited. In short, by structuring this process we are narrowing the artistic or personal content of the models.

Applied work in systems modeling and simulation has been particularly weak regarding this aspect of model construction. That is, models presented in the literature usually evolve from provisional specifications. In fact, the
flexibility of this evolutionary process is sometimes mentioned as an advantage of the approach and the resulting models. The unfortunate result of this approach, however, is that the scientific community interested in the research must often accept or reject the model on faith alone. While this may be acceptable from a functional and positive view, it makes the accumulation of knowledge on the system in question an inefficient process.

Adaptive Models

The preceding discussion concluded that iterative procedures by which systems models are typically constructed might be productively viewed within the context of an adaptive control framework. Choices of optimal decisions with respect to model specification and revision when viewed in an adaptive control framework are concerned with the dual effects of the improvement in the objective function which occurs as an indirect result of more reliable structure estimates and the more usual direct effects of setting the controls. Attractive features of this approach for economic decision problems are discussed in Aoki [1974], Chow [1975], Prescott [1967, 1971, 1972], Rausser and Freebairn [1974a, 1974b], Tse [1974], and Zellner [1971]. After a review of the essentials of the adaptive control formulation of sequential decision problems in the following section, the framework is shown to apply also to decision problems arising in model construction.

Decision and economic policy problems. The adaptive control framework in the context of economic decision problems involves a number of components: (1) Specification of the relevant decision maker(s) and the control or instrument variables available for manipulation. Decision points and procedures for revision of policy decisions, in the light of new information, should also be noted. (2) Specification of an objective function ranking the desirability of different states of the system. Arguments in this function are certain key performance variables, including endogenous and control variables, thought by the policy or decision makers to have significant implications for the problem under study. (3) Specification of constraints or a policy possibility set which includes (a) state transformation functions relating the internally determined variables in each period to the policy variables, other exogenous variables, and lagged variables describing the beginning state of the system, (b) initial conditions for the system, and (c) other constraints delineating the feasible control variable and endogenous variable spaces. (4) Specification of the processes of information generation, together with prescriptions for the analysis of data by policy makers as the decision sequence proceeds. The fourth component embraces mathematical learning processes whereby the additional information may be used to lessen initial uncertainties about objectives, the constraint functions, and states of the system.
In short, adaptive control methods are dynamic optimizing procedures (applied to multiperiod decision problems) in which imperfect knowledge is a key characteristic. A discrete period, sequential decision making process is assumed. In each decision period a policy is selected from a set of feasible actions so as to maximize the objective function. The constraint functions delineate the feasible policy space and specify the endogenous variables included in the objective function in terms of the instrument environmental or conditioning variables and the initial state of the system.

Operationally, uncertainty arises principally with respect to the effects of alternative policy actions on various performance variables, i.e., the constraint or transformation functions. Typically, the constraint functions are based on an approximated model of the system under consideration. A common (simplifying) procedure has been to estimate the model first (using the term in the general sense suggested earlier) and then to derive the "optimal" policy assuming the provisional parameter estimates are equal to their "true" values, where possible recognizing uncertainty of future exogenous variables and additive random disturbances which enter the model. Procedures for solving problems of this type involve the concept of certainty equivalence (Chow [1972], Holt [1962], Simon [1956], Theil [1964]). Treating the parameters as known with certainty, however, is obviously unsatisfactory. They are, in general, only approximations of the true but unknown, or perhaps even random, parameters.

The imperfect knowledge of the relationships comprising the constraints which specify effects of alternative policy decisions may be viewed as resulting from four major sources: (1) approximations, including omitted variables, simplifying mathematical functions, and various forms of aggregation which lead to the inclusion of stochastic rather than deterministic relationships; (2) data limitations (small samples); (3) structural changes; and (4) the future environment (uncertainty about future values of the noncontrollable or environmental variables).

Adaptive control methods explicitly recognize that as a system progresses through the sequence of periods data become available which can be used to update or revise the decision maker's perception of the policy possibility set. These revisions, in general, should not be regarded as separate from the derivation of an optimal policy. Alternative decisions may reveal more or less information about the actual system via different sets of the resulting data obtained. The inherent benefits of the additional information depend upon whether or not an "improved" representation of the structure results in superior future control. The incurred costs of such information emanate, in part, from the choice of a current policy which is less than optimal from a pure control point of view. In short, the optimal policy may involve decisions
which are of a dual nature, particularly if losses associated with current decisions can be recovered in subsequent periods by utilizing improved information on the structure.

As previously noted, the adaptive control approach to decision and economic policy problems corresponds to Bellman's approach [1961, pp. 198-209] as well as Fel'dbaum's third class of control systems [1965, pp. 24-31]. In effect, optimal adaptive controls require a simultaneous solution to combined control and sequential experimental design problems and thus are dual in nature. This dual nature is characterized by three elements.

The first element concerns the direct effect of decisions on the criterion function. The total effects may include these direct effects of the decision variables themselves and, through the transformation functions relating the system at different states, their indirect effects on current and future values of the state or endogenous variables.

The second element is concerned with the learning process. Closed-loop control policies for each period, presuming the existence of a set of sufficient statistics, are conditioned on information related to the current state of the system and on the most recent estimate of the probability distribution function for the unknown elements of the decision problem. With respect to the unknown elements, as we proceed into the future additional sample information becomes available. These data additions allow learning to take place regarding, for example, unknown coefficients of the constraint functions. Formal procedures for utilizing sample additions to update probability distribution specifications include Bayesian methods, least squares revision methods, Kalman-type filters, as well as others. (For a discussion of Kalman-type filters, see Kalman [1960]; for an exposition of least squares revision methods, see Albert and Sittler [1965] and Freebairn and Rausser [1974]).

The third element concerns experimental design. Adaptive control strategies are conditional functions depending in part on the moments of the probability distribution functions for the unknown components of the decision problem. Normally, the expected value of the criterion function resulting from these strategies is improved, the more concentrated the probability function is about its expected value. Note also that the properties of the revised probability distribution functions (on which future decisions are based) depend on available sample information. Current decisions can influence the sample information which is generated and thus becomes available over future control periods. Since this information has a direct bearing on future estimates of the probability distribution functions and these in turn influence the efficiency of future decisions, an experimental dimension is involved in current actions.

The above considerations and implied models have been notably lacking
in applications of systems and simulation to the various empirical problems in agricultural economics (Burt [1969]). Illustrative applications of these considerations are available in Rausser and Freebairn [1974a] and Rausser [1974a]. A more heuristic application, numerically exploring alternative policies, has been developed by Boehlje and Eisgruber [1972]. Engineers have also examined the applicability of these concepts to economic problems. Examples of these applications include the work of Buchanan and Norton [1971], Murphy [1968], and Perkins, Cruz, and Sundararajan [1972]. Formulations of adaptive control models have also been employed in mathematical and engineering fields, at least, in a theoretical context (Aoki [1967], Anstrom and Wittenmark [1971], Bar-Shalom and Sivan [1969], Bellman and Kalaba [1959], Curry [1970], Early and Early [1972], Gunckel and Franklin [1963], Kogan [1966], Tarn [1971], and Tse and Athans [1970, 1972]). From the viewpoint of economic policy the adaptive control formulation represents an extension of the pioneering models advanced by Tinbergen [1952].

Formally the adaptive control problem may be specified in this way: Find the sequence of conditional policy strategies $u_t^* (P^{t-1}, y_{t-1})$, $t = 1, 2, \ldots, T$, to maximize

$$J = E \left[ W(y_1, u_1, y_2, u_2, \ldots, y_T, u_T) \right]$$

subject to

$$y_t = \Phi_t (y_{t-1}, u_t, x_t, e_t) = \Phi_t (Z_t, e_t)$$

where $Z_t = [y_{t-1}, u_t, x_t]$

$$(3) \quad P^T(\Phi_t, e^T, x^T_t) = I_t [P^{t-1} (\Phi^T_{t-1}, x_{t-1}^T), y_t, z_t]$$

where $\Phi_t = (\Phi_t, \Phi_{t+1}, \ldots, \Phi_T) e^T_t = (e_t, e_{t+1}, \ldots, e_T) x^T_t = (x_t, x_{t+1}, \ldots, x_T)$

$$(4) \quad y_t \in Y_t, u_t \in U_t,$$

$$(5) \quad y_0 = y(0), \text{ and}$$

$$(6) \quad P^0 (\Phi^T_0, e^T_0, x^T_0 = P (0))$$

In the preceding formulation $W$ is the objective function, $E$ is the expectation operator, $y_t$ is an $n \times 1$ vector of endogenous or state variables, $u_t$ is an $m \times 1$ vector of control variables, $x_t$ is an $\ell \times 1$ vector of noncontrollable exogenous variables, and $e_t$ is an $n \times 1$ vector of disturbance terms. The function $P^T(.)$ denotes the joint probability distribution or its set of sufficient statistics conceived at time $t$. The sets $Y_t$ and $U_t$ represent $n$- and $m$-dimensional Euclidean vector spaces and are referred to as the admissible set of
state and control variables, respectively. The n-dimensional vector, \( y(o) \), denotes the initial prior probability distribution function.

The above specification assumes that the unknown components of the problem, \( \Phi, e, \) and \( x \), are concerned only with transformation functions (2). The objective or preference function, the planning horizon (T), and the initial conditions are presumed known. Furthermore, the state vectors \( y_t \) are assumed to be measured accurately (that is, the state of the system is completely accessible in each of the \( t \) periods). Note that the probability distribution functions (3) are sufficiently general to allow for the case in which distributions of the stochastic elements are known as well as the case in which these distributions are unknown. For the latter case, moments of the probability distributions are assumed to be stochastic and some a priori probability density for these moments is presumed to be available. Usually the disturbance terms \( e_t \) are assumed to have zero expectation and to be intertemporally independent and identically distributed. This assumption can be relaxed, but at an increase in the cost of computations. Also multiple lag systems and measurement errors and delays in observing state or noncontrollable exogenous variables can be explicitly incorporated by operating with appropriately augmented constraint functions (2), or state vectors (Aoki [1967]). For constraint structures involving multiple lags, a state-space representation may be easily derived (Rausser [1974b]). Note also that three properties must be satisfied before the adaptive control or any other dynamic model representation can be given a meaningful interpretation. These properties are stability, controllability, and observability. Economists are familiar with stability analysis but are less familiar with the other two properties. The controllability property is concerned with reconstructability—that is, it is possible to uncover or recover unobservable system data. For a discussion of these properties and their importance in constructing systems models, see Aoki [1975].

**Adaptive model construction.** The adaptive control framework just described can be utilized to provide a basis for structuring the model revision process. As previously noted ad hoc revision processes can be viewed as involving inefficient use of the information gained from provisional specifications and as resulting in highly personalized final models. The attractive feature of the adaptive control framework in this context is not so much that it presents a basis for deriving a unique optimal path for the development of research models but that it provides a unifying set of activities for model construction and a norm against which the personalized strategies can be compared.

As noted later in the survey of applications, systems models applied to descriptive, behavioral, forecasting, and decision problems in agricultural economics are typically highly specialized to particular situations. Researchers
begin with some concepts from theory, results of other applied work, perhaps some personal views, and historical data on the system to develop a provisioningal specification. Given constraints which exist with respect to resources available for the research project and the time frame within which the research is planned, the analyst proceeds from one provisional specification to another until a version of the model is available which, given the constraints, satisfies the objectives of the research endeavor. For institutional reasons, owing to the existence of experiment station projects, the objectives of the research process are usually stated in rather precise terms. Research budgets, available time, and other constraints are also known with a fair degree of certainty. As with the conventional adaptive control problem, one important issue is the uncertainty with respect to the effect of actions taken by the researcher on the ultimate modeling objective. By recognizing the process of proceeding from one provisional structure to another as a transition between states in the implicit control problem and by making more explicit the policy or strategy governing the evolution to the final version of the model, research involving systems models can be placed on a sound scientific footing. The availability of such information on model construction and the formalization of the implicit control problem provide a firm basis for critical appraisal of the resulting formulation and at the same time establish the foundation for a more systematic process of knowledge accumulation.

**Model types.** Special cases associated with the application of adaptive control concepts in developing model representations of systems may be viewed in terms of the various model types. For descriptive models the objective function would be stated incorporating the reliability with which the parameters describing the relations or systems in question can be obtained. Constraints would involve the untestable hypotheses governing the basic structure, assumptions about the probabilistic nature of the structure being estimated, and research budget restrictions. Given this situation, the researcher is in a position to view alternative strategies for developing the descriptive model as competing policies for the solution of the implicit control problem. Formalizing and structuring the associated learning processes may contribute to the ability to assess competing descriptive models and may provide a basis for contemplated extensions.

For behavioral and forecasting models the approach suggested by the adaptive framework is essentially the same. The major difference is of course in the formulation of the objective function. Different model purposes imply the inclusion of different arguments in the objective function used to evaluate the performance of the model construction process (Cooper [1972]). In the case of behavioral models emphasis is typically placed upon the reliability of specified causal relations. For forecasting models the objective would
involve the properties of the forecast values vis-à-vis preconceptions about the operation of the system being studied and/or the observed outcomes for system variables.

In decision problems the adaptive control approach may be applied directly. The effectiveness of decision models is contingent upon the accuracy with which the system to be regulated has been characterized. Hence, development of an adequate model representation is just a component of the more general problem motivating the formulation of the decision model. The only differences occur when the development of the decision model takes place apart from the solution to the decision problem. It has been shown elsewhere (Fisher [1962]) that this approach to the solution of decision problems generally results in policies inferior to those which obtain when estimation is an integral part of the problem.

Tractability

The framework proposed for adaptive model construction is obviously demanding. In fact, solutions to the associated adaptive control problems of the type encountered in model construction are as yet limited to highly simplified structures. Even for the case of a quadratic objective function and linear constraints, it is presently impossible to express the optimal adaptive control explicitly in analytic form (Aoki [1967]). Furthermore, numerical solution procedures rapidly encounter the “curse of dimensionality” for even modest control problems. The simple and pedagogic models found in Marschak [1963] and Ying [1967] illustrate this computational burden.

Approximations to solutions are possible, however, and, although not currently viewed as such, they are the object of most simulations of systems models. From this perspective the tractability problem of model construction becomes somewhat different. Recognizing that a closed-form solution to the model construction process as posed in the previous discussion is possible only in highly restrictive cases (Tse and Bar-Shalom [1973], Tse, Bar-Shalom, and Meier [1973]), various feasible, near-optimal solutions may be applied routinely in the construction and operation of systems models.

The complexity this observation adds to the process of systems analysis is related to choices of models and tractability. On one hand, a model might be designed which could be specialized for a particular system by a rather routine application of the adaptive control framework. More complicated models, on the other hand, may prohibit such an application and thus become more highly personalized than the researcher might wish.

System versus model approximations. Models, in general, involve approximations of the system being studied—approximations in the sense that they are abstractions necessary to achieve useful research results. These approxima-
Solutions are a function of available knowledge of the system along with specifications required to serve the purpose(s) for which the model is constructed.

Since models are themselves systems, similar observations apply to approximations of models. This relationship is particularly important for the tractability problem. It suggests that researchers might find it worthwhile to use approximations of their models. Solutions to the control problem as formulated for the more simplified models could then be used in developing research strategies for the more complex model representations. If such simplifications can be made on systematic mathematical grounds (for example, Taylor's series approximations, stochastic structure, and so on), then the observations derived from these research strategies and subsequently applied to similar but more elaborate models may have greater generality. The previously noted value of the adaptive control framework would suggest that this approach, although not novel, could prove quite productive.

**Analytical versus ad hoc simulation.** Information gained at the various stages in the systems modeling process frequently occurs as a result of simulating provisional structures. The previous discussion has indicated that there is a choice about how such simulations or experiments might be conducted. If conducted on an ad hoc basis, they may contain less information than if systematically (analytically) structured. Given such a framework, design of the experiments can be viewed as an approximating procedure. Advantages of such optimum seeking procedures over ad hoc methods are widely accepted in economics. Hence, there is yet another reason for seriously considering the tractability problem in the design of systems models. More will be said later about the use of experimental designs. It suffices for now to indicate that recognition of this choice provides the basis for a useful link between the literature on systems and simulation and some rich results relating to optimal designs and evolutionary experimental procedures.

**Simulation**

Simulation is the method by which experimental information about systems or models of systems is generated. It is used in formulating, evaluating, and applying models of systems. These methods range from ad hoc trials to highly structured procedures used for numerical approximations (Naylor, Wertz, and Wonnacott [1967, 1968]). In this section we discuss major types of simulation and systems modeling.

**Analogs**

Most applications of systems concepts begin with the construction of a symbolic model. These symbolic models may incorporate flow charts, alge-
braic statements, and various types of physical items. Although such formulations may be useful in aiding the conceptualization of the system being studied, they do not necessarily lend themselves to experimental processes. The exception is of course when the statement of the model is itself a computer program.

To simulate a model, it is frequently necessary to convert it into a form more convenient for the intended trials. These alternative constructs are typically physical or digital analogs. When they are isomorphic to the algebraic statement of the model, results of the experiments conducted using them can be more effectively employed as a basis for studying the function of the model or system.

Physical analogs are most commonly used in gaming, teaching, and behavioral types of activities. Gaming models are always at least partially physical in nature. Models used in teaching and in extension activities also tend to be physical since they are set in an interactive operative mode. Finally, many behavioral experiments are physical analogs. Consumer panels used in determining attitudes and preferences are illustrative of the physical analogs used in behavioral investigations.

Physical models or analogs have been less important in agricultural economics than in other applied sciences. The extensive use of prototypes and analog computers in engineering, for example, finds few counterparts in agricultural economics. However, the behavioral option, particularly in the context of "experimental economics" has the most potential for further application (Naylor [1972], V. L. Smith [1962]).

Digital analogs are used in computer simulations. It is in this area that the impact of the current computer technology on systems studies is most evident. Such analogs can be constructed using any of a number of programming languages currently available. In fact, the concern with programming efficiency led early investigators to develop special purpose computer languages.

There are several levels of communication which correspond directly to machine functions. At a higher level, assembly languages are mnemonic symbols which are defined in terms of, and can be translated into, basic machine language. A compiler is a program which accepts statements written in complex and high-level languages and converts them to basic machine language. Most compilers are problem oriented and different from machine and assembly languages. They are composed of language symbols and operations required by a special type of problem. COBAL, for instance, is a problem oriented language applicable to problems involved in the data handling aspects of accounting. Finally, simulation programming languages are just special types of problem oriented languages. In fact, it is worth noting that these special-purpose languages have developed in an evolutionary manner usually
in association with large and extended investigations involving the simulation of various systems models (Kiviat [1967], Krasnow and Merikallio [1964]).

As these languages are designed to facilitate experiments with particular types of models, it is natural to conclude that their principal objectives are (1) to provide data representations that permit straightforward and efficient modeling, (2) to permit the facile portrayal and reproduction of dynamics within modeling systems, and (3) to facilitate the study of stochastic systems (that is, they contain procedures for the generation and analysis of random variables) and time series.

Aside from these common objectives, even the more general simulation programming languages are problem focused. For example, SIMSCRIPT II is an event-oriented language and therefore is useful in simulating systems which can be viewed as sequences of events with particular types of attributes. Various types of management and behavioral problems lend themselves to simulations with this special programming language (Kiviat, Villaneuva, and Markowitz [1968]). DYNAMO is a special-purpose language used to study closed systems of continuous variables in which the broad characteristics of information feedback within the system are important attributes in determining dynamic performance. This language was developed in connection with the industrial dynamics advanced by Forrester [1961]. SIMULATE, developed by Holt et al. [1965] is concerned with capturing those parameters and decision variables critical in the determination of model stability.

CSL is an activity-oriented language (IBM [1966a]) useful for simulating models based upon systems involving queues, waiting lines, sequencing of events in an efficient manner, and the like. GPSS is a transaction language (IBM [1966b]) which can be used to simulate problems involving efficient processing of individuals, ships, and cars.

In summary, these special-purpose computer languages facilitate simulation of various types of systems models. They are somewhat more removed from the basic languages than the common scientific computer languages such as FORTRAN and require more elaborate compilers. However, they tend to facilitate the processing of particular types of statements or commands in a very efficient manner. Current trends are for these special language characteristics to be integrated into more versatile computer programming languages (Naylor [1971]). Unless substantial amounts of simulation of a particular type are anticipated or the simulation problems require very specialized language features, investments in such languages for applied researchers do not appear to be economical.

Verification

Uses of simulation in verification are commonplace in the agricultural
economics applications, especially when the models and analogs are digital. As most applications of systems methods incorporate digital models or analogs, we confine examination of verification to its use in the context of computer simulation. As noted previously, this process is mechanical and is intended to determine whether the digital analog operates in accord with the model specification.

Digital models of systems are often large and complex both in terms of program logic and stochastic structure. Moreover, the models are generally of dynamic systems. The first step in the process should therefore include checks for syntax and other possible specification and programming errors. Secondly, the output variables may require checking (say, with the sample data) to appraise the ability of the program to reproduce the data on which it is based.

In these verification processes the logic of the model is appraised numerically. In this sense, acceptable results are not always reassuring for the possibility of obtaining unacceptable ones, especially if the model is stochastic. Another difficulty arises from comparisons of outputs with data. This might be done, for example, to see whether the summarizations of the observed data (say, for some type of multivariate distribution or stochastic process) are appropriate. Since these models frequently include statistics which are not sufficient and prior information which has not been efficiently combined with the observed data, the comparisons may be inconclusive for verification.

Validation

The appropriateness of a particular model of a system can be viewed from two standpoints. First, as is commonly done, the performance of the structure can be investigated for its ability to reproduce or predict the variables in the system which are internally determined. When these investigations can be performed on a sampling basis, useful statistical results are available for evaluating and choosing between possible structural models (Rausser and Johnson [1975]). Second, models of large and complex systems are likely to employ specifications implied by normative propositions. As much of the structural specification may follow from these propositions, it is natural to assess their generality in corroborating the model with the system. This of course takes us away from the positivistic approach to validation and into some more general philosophical questions (G. L. Johnson and Zerby [1973], Kuhn [1970]).

PHILOSOPHICAL ISSUES

Application of Kuhn's [1970] notion of a paradigm to economics is becoming increasingly fashionable. In the present context it is useful to note that a paradigm typically defines a large set of possible hypotheses and makes no claims for the validity of any particular member of that set. Paradigms,
unlike the hypotheses to which they give rise, cannot be validated by experimental or statistical methods. For example, the purely competitive model is not a hypothesis but a paradigm; although a specific hypothesis embodying some version of the competitive model can, in principle, be tested, the competitive model cannot. This does not suggest that the competitive model ought to be abandoned. On the contrary, since abstractions from details are essential, usable models must be misspecifications of the system to which they refer. The only option is to construct models which fall short of a complete specification of the system under examination. In this sense all model representations are partially reduced forms (owing to omission of variables, distortion of relationships, aggregation) even though frequently identified as structural models. It is always possible to imagine a more fundamental explanation of the phenomenon under examination involving more equations and thus internally determined variables. Hence it appears reasonable to suggest (1) that models cannot be solely judged by the resemblance between their specification and the systems which they are designed to represent and (2) that the choice of different model specifications of the same system by different investigators implies no presumption that one of them must be in error. For these reasons, it is safer to investigate "sufficiency" (the adequacy of the constructed model for the purposes designed) than "realism."

THE CLASSICAL SITUATION

When considered in connection with alternative structural specifications (and methods of estimating parameters), the classical concept of validation becomes rather vague. Classical statistical techniques of validating estimated relationships are in principle straightforward (Ramsey [1969], Ramsey and Zarembka [1971]). Data required for an assumed structure are obtained through sampling the population, and parameters are estimated and inferences are made on the basis of sampling distributions of the statistics. Under sufficiently strong distributional assumptions the process of establishing the validity of the model is a matter of examining its predictive power as well as agreement of the estimated parameters with qualitative restrictions implied by the underlying theory. Acceptable parameter values and accurate predictions are also standards by which the validity of more general types of systems models may be evaluated. Methods for examining properties of these structural models are, however, far from standard (Rausser and Johnson [1975]).

ALTERNATIVE STRUCTURAL SPECIFICATIONS

The first point of departure from the classical situation is the possibility of alternative structural specifications. As the theoretical basis for systems
### Evaluation Criteria for Investigating the Explanatory and Predictive Power of Systems Models

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<th>Point Criteria</th>
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<td><strong>Criteria</strong></td>
<td>1. Coefficient of multiple determination&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1. Mean forecast error&lt;sup&gt;c&lt;/sup&gt; (changes and levels)</td>
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<td>2. Durbin-Watson statistic&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2. Mean absolute forecast error&lt;sup&gt;c&lt;/sup&gt; (changes and levels)</td>
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<td>3. Graphical analysis of residuals</td>
<td>3. Mean squared forecast error&lt;sup&gt;c&lt;/sup&gt; (changes and levels)</td>
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<td>4. t statistic&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4. Any of the above relative to&lt;sup&gt;c&lt;/sup&gt;</td>
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<td>5. Chi-square or F statistics&lt;sup&gt;b&lt;/sup&gt;</td>
<td>a. the level or variability of the predicted variable</td>
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<td>6. Aitchison-Silvey test [1958] of a priori restrictions</td>
<td>b. a measure of “acceptable” forecast error for alternative forecasting needs and horizons</td>
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<td>7. Ramsey specifications error tests [1969]&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>a. omitted variable test</td>
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<td>e. chi-square “goodness-of-fit” test for normality</td>
<td>7. Theil’s inequality coefficient&lt;sup&gt;e&lt;/sup&gt;</td>
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<td>8. Sample mean squared error&lt;sup&gt;c&lt;/sup&gt; (changes and levels)</td>
<td>8. Information inaccuracy statistics for nonsample data</td>
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<td>9. Information inaccuracy statistics for sample data</td>
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<p>| Tracking Criteria              | 1. Number of sample turning points missed                                   | 1. Number of nonsample turning points missed                               |
|                                | 2. Number of turning points falsely explained                              | 2. Number of turning points falsely predicted                             |
|                                | 3. Number of sample under or over estimations                              | 3. Number of nonsample under or over prediction                           |</p>
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<th>Explanatory</th>
<th>Predictive&lt;sup&gt;d&lt;/sup&gt;</th>
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<td>4. Rank correlation of $\Delta \hat{y}_t$ and $\Delta y_t$</td>
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<td>5. Test of randomness for directional explanations</td>
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<td>6. Test of randomness for explained turning points</td>
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<td>7. Information theory statistics for sample data&lt;sup&gt;g&lt;/sup&gt;</td>
<td>7. Information theory statistics for nonsample data&lt;sup&gt;g&lt;/sup&gt;</td>
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**Error Criteria**

1. Bias and variance of explained error
2. Errors in start-up position versus errors in explained changes ($\Delta \hat{y}_t$)
3. Comparison with various "naive" explanations
4. Comparison with indicator qualitative errors

**Spectral Criteria**

1. Comparison of power spectra for estimated and sample data series
2. Spectral serial correlation test of structural or reduced form sample disturbances
3. Cross-spectral statistics of relationships between estimated and actual sample values

**Explanatory**

This measure, like a number of the other measures presented, is strictly applicable only to single-equation models. Some multiple-equation counterparts of this measure are discussed in Dhrymes et al. [1972].

<sup>b</sup>These criteria represent only approximate small-sample tests if the assumptions of the classical model are not fulfilled (Ramsey [1969]).

<sup>c</sup>Classical hypothesis testing procedures cannot be employed for these statistics since their small-sample properties are generally unknown.

<sup>d</sup>This column is adapted from Dhrymes et al. [1972].

<sup>e</sup>For a critical appraisal of this predictive criterion, see Jorgenson et al. [1970].

<sup>f</sup>$\hat{y}_t$ denotes values of endogenous variables obtained from the model, $y_t$ is the corresponding observation, $t = 1, \ldots, T$. For the prediction of nonsample observation period, $n = T + 1, \ldots, T + m$, a similar designation.

<sup>g</sup>These statistics are descriptive measures of observed (explained and unexplained), model (correct and incorrect), and joint (corresponding and noncorresponding) information.
analysis is far from complete, this is the usual situation (Heady [1971], H. G. Johnson [1951], Thorbecke [1971]). At issue is the comparative validity of the two or more structural models. A host of alternative evaluation criteria can be utilized in assessing the validity of alternative systems models. As some authors have suggested, these various criteria should be examined in the context of a “Sherlock Holmes inference” approach—that is, a process of data analysis involving Sherlock the analyst assembling bits of evidence to produce a plausible story (Dhrymes et al. [1972]). This evaluation may involve attempts to determine both explanatory and predictive powers of the systems models.

Criteria advanced to examine the explanatory (nonpredictive) power of systems models are associated with comparisons of estimated and sample values of internally determined variables. Specifically, conventional measures of “goodness of fit” complemented by “change of direction” tests or tracking criteria assume importance in this context. A number of tests that might be employed to evaluate the explanatory power of systems models are indicated in the accompanying list. They are most meaningful when parameters of the models have been systematically estimated without recourse to artificial conditioning variables (for example, time counters in time series data). In systems models with substantial numbers of dummy shift variables and time counters these internal consistency tests lose much of their value. Little is revealed about the validity of the model from consistency tests in such instances since the model becomes simply a mechanism for reproducing the sample data.

Comparing alternative models on the basis of their explanatory power rests on the idea that the model which explains the sample data best is most valid. Comparisons of this type are difficult since some model representations may perform well on the basis of one or more criteria but poorly on the basis of others. Thus a weighting scheme of some sort is required. Generally, the degree of model validity increases with the number of positive results registered.

These explanatory comparisons are frequently based either on analysis of variance and results of test statistics widely used in statistical inference or on direct comparisons of the estimated values of the jointly determined variables with sample data. In the former case comparisons can be made by testing differences in explanatory powers of reduced forms (Dhrymes et al. [1972]). In the latter case a number of alternatives are available for evaluating the “goodness of fit” of the simulated series and sample data. These tests range from classical chi-square analysis to more sophisticated comparisons involving the use of spectral analysis (Fishman and Kiviat [1967], Howrey [1971], Rausser and Johnson [1975]). Comparison of simulated and actual series seems to be a natural alternative for evaluating validity, although (as noted below) it has distinct limitations.
With nonsample data available alternative models can be compared on the basis of their ability to forecast or predict values of the endogenous or internally determined variables. An evaluation of the predictive power of alternatives systems models represents a more formidable examination than the evaluation of the explanatory power of such models. Typically, a wide variety of alternative models or theories presents approximately equivalent degrees of validity on the basis of explanatory or "goodness of fit" criteria. As a consequence, more stringent predictive performance criteria are usually sought. A number of these are included in the list of evaluation criteria. Each involves an assessment of the homogeneity of predictions for alternative models with nonsample data.

Model comparisons based on predictive criteria appear to be made better on an ex post rather than an ex ante basis. With ex post predictions observed values of the exogenous or conditioning variables can be utilized. All errors then result from the structural specification and parameter estimates. No impurities are created by errors in forecasting the values of the exogenous variables. There are few special situations (involving linear systems models and well-behaved error terms) in which forecasting performance procedures yield classical statistical tests (Jorgenson, Hunter, and Nadiri [1970], Dhrymes et al. [1972]). In the more general situations, however, no statistical tests appear to be available at this time. This simply reflects the fact that statisticians have not yet succeeded in developing techniques for evaluating sequences of dynamically generated forecasts for a set of jointly determined variables.

For systems models one departure from the classical situation which frequently arises is data availability. Current experience reveals that sufficient data are not available for the larger systems models (Dudley and Burt [1973], Fletcher, Graber, Merrill, and Thorbecke [1970], Halter, Hayenga, and Manetsch [1970], Manetsch, Hayenga, et al. [1971], Thorbecke [1971]). As indicated, the only alternative is to supply missing or nonestimable parameter values from prior knowledge, based either on experience with similar relationships from corresponding situations or on educated guesses. The adaptive estimation procedures required in the case of insufficient data leave little to salvage in terms of classical validation methods (Van Horn [1971]). Predictive tests based on sample data have less meaning owing to the sequential or adaptive estimation procedures. Tests of estimates of individual parameters are also of limited value for the same reasons. Finally, it is highly unlikely that scarce data will be reserved for testing the model. When data limitation problems are considered along with problems of alternative structural representations, it is clear that conventional approaches to validation are largely uninformative. The inconclusiveness of these approaches has led researchers to use internal consistency to examine large-scale and nonlinear systems models.
INTERNAL CONSISTENCY

Suppose a model describing a system has been estimated and tested where possible with classical statistical procedures. If the results of this first validation procedure are not convincing, further information on the validity of the structural model may be sought. One source of such information is an investigation of the dynamic implications of the system representation. If these dynamic implications corroborate the established theory on the functioning of the system, then the investigation yields results which support the validity of the model. On the other hand, if the dynamic implications do not corroborate the theory and institutional knowledge, the validity of the model may be questioned.

There are well-established methods for investigating the dynamic implications of both linear and nonlinear structural models (Adelman and Adelman [1959], Evans [1969], Fishman and Kiviat [1967], Howrey [1971], Howrey and Kelejian [1971], Howrey and Klein [1972], Rausser and Johnson [1975]). These methods are based upon the fact that lagged relationships in systems models can be viewed as difference or differential equations. Aside from straightforward impact multiplier analyses based directly on the reduced forms, other types of multipliers (for example, interim, cumulated, and equilibrium multipliers) based on final forms or solutions of difference equations can be used for examinations of stability and convergence. Applications of methods for examining internal consistency typically proceed by using the estimated reduced form. The procedure is to insert the partially tested estimates of the structural parameters, obtain the reduced form, and determine its dynamic properties. Other forms of the model can also be employed to ascertain the dynamic properties of the structural model. For further details, see Rausser [1974a].

Both analytical and simulation methods can be used to examine the properties of systems of the type usually encountered (Fishman [1967], Fishman and Kiviat [1967], Howrey and Kelejian [1969], Naylor [1970], Rausser and Johnson [1975]). Although there is currently some disagreement about the circumstances under which one general method is preferred to another, the following guidelines seem reasonable (Howrey and Kelejian [1969], Naylor [1970]). For nonstochastic and comparatively simple linear and nonlinear models analytical methods offer advantages to ad hoc simulations (Howrey and Kelejian [1969], Rausser and Johnson [1975]). As the models become large and sampling or prior distributions of the parameter estimates as well as the stochastic disturbances entering the system are recognized, simulation methods seem to be more tractable means of obtaining information about the dynamic behavior of the system (Nagar [1969]). Although simula-
tion methods have the advantage of being applied to the structural form of the model, the general implications of the simulated series are in many cases unclear. Hence, ad hoc simulation as a means of obtaining dynamic properties is recommended only when analytical methods or analytical simulation methods are not feasible (Rausser and Johnson [1975]).

NORMATIVE CONSIDERATIONS

Models of economic systems are typically behavioral in nature. The behavioral expressions incorporated in the structures of such models may be distilled from previous empirical and theoretical investigations or may be descriptive as in the case of firm or process systems models. The behavioralist view is that these relationships are descriptive and do not require inquiries about their normative underpinnings. The positive view would assert that the implicit normative assumptions contained in the behavioral specifications are unimportant. If the model containing these behavioral conditions lacks predictive power, then its use is rejected. Neither of these approaches, however, represents a very comfortable position for applied models of economic systems (G. L. Johnson and Zerby [1973]). It is well known that specifications of individual supply and demand functions involve normative considerations. In the purely competitive theory we are tightly confined by a paradigm. Departures tend to include implicit value judgments about the advisability of concentration in industries, land reforms, income redistributions, and so on. It is pleasant to contemplate generating such statements or relations from primitive and widely acceptable normative assumptions and thus capturing a detailed specification of the paradigm governing the model. However, economic theory is not rich enough to provide such a structure for models of complex economic systems. We are left, therefore, with models including behavioral relationships which involve nonprimitive and possibly conflicting normative assumptions.

Experimentation

Two observations have been made regarding simulation. First, it is a method of experimenting with models of systems. Second, given the purposeful intent of simulation whether used in model construction or application, it is beneficial to systematize choices of design points. The second observation follows naturally if simulation processes are viewed within a control framework. Methods of systematizing experiments with systems models as they relate to experimental design are considered in this section.

SENSITIVITY ANALYSIS

Sensitivity analysis is simply the process of gathering information with
which to evaluate the robustness of decisions taken in constructing and applying models (Maffei [1958]). In model construction, for example, the internally determined variables may be examined for their sensitivity to choices in parameters, structure, or environmental conditioning variables. The corresponding sensitivity or variation would of course be evaluated using an implicit or explicit criterion function. Applications, whether for descriptive, behavioral, forecasting, or decision models, can be subjected to similar types of evaluations.

In sensitivity analysis interest is directed to areas where doubt, uncertainty, and ignorance are greatest. A model which is very sensitive to changes in assumptions about which there is substantial uncertainty will warrant skepticism. A useful distinction to keep in mind in this regard is the difference between local and global sensitivity (Zellner and Peck [1973]). In a local sense many models may be insensitive to changes in exogenous factors, parameters, and so on, but very sensitive to such changes in a global sense. For these situations, the investigator should report the “range” of the constructed model’s robustness.

The important aspect of sensitivity analysis, in general, is its experimental nature. Hence, in selecting the trials or experiments to be conducted in a sensitivity examination, the researcher can choose between ad hoc and formal experimental design settings. The literature relating to the advantages and disadvantages of such choices is extensive. (See Burdick and Naylor [1966], Fishman [1971a, 1971b], From [1969], Friedman [1971], Gordon [1970], and Kleijnen [1974, 1975].) The advantage of making experimental design choices is of course associated with the increase in information which results from a systematic selection of the experiments (Hufschmidt [1962], Hunter and Naylor [1970]).

Application of experimental designs methods to problems of model sensitivity have received increased attention in the literature. Ignall [1972], Naylor [1970], Naylor, Burdick, and Sasser [1967], and Zellner and Peck [1973] illustrate the use of these methods and the types of results that can be obtained. Methods employed in designing simulation experiments have been rather routine. Complete factorial experiments are by far the most common. It is clear, however, that as familiarity with experimental methods increases more sophisticated designs will be employed (Kleijnen [1974]). Such designs are particularly valuable when specialized types of information are sought or when the number of factors and levels make a complete factorial experiment infeasible (Kleijnen [1975]). The advantage of the more specialized techniques is that trade-offs for the designs are known in advance (Handscomb [1969]). That is, the researcher using such a design would know which hypotheses are maintained and which are testable given the choices on
factors, factor levels, design points, spread, and center. Extensive reviews and expositional treatments of complete factorial, incomplete block, composite, and other more common types of experimental designs useful in systems work are contained in John [1971], Mendenhall [1968], and Kleijnen [1974, 1975].

RESPONSE SURFACES

Response surfaces are simply functional relationships between parameters, environmental variables, structural choices, and, perhaps, criterion functions and internally determined variables (Naylor, Burdick, and Sasser [1967]). Such surfaces may be used in evaluating dynamic properties of models, corroborating them with information from the system, determining internal properties or consistency, and verification. As with sensitivity analysis it is important to recognize that when such relationships cannot be obtained as closed-form solutions, numerical approximation procedures must be employed which are in fact experiments. Again, the investigator is faced with the problem of systematic versus ad hoc choices of the factors selected for examination.

The literature on response surfaces is rich and contains well-developed procedures which have substantial potential for systems studies. The first applications in an agricultural context, though not to systems models as such, were made by Finney [1945]. More recent work on the study of response surfaces, however, dates from important papers by Box [1954] and Box and Wilson [1951]. These papers contain clear statements of the philosophical basis for response surface examination and sequential experimental designs. The latter problem amounts to a multistage exploratory investigation of response surfaces.

In relating the statistical literature to systems studies we should first indicate an important point of distinction. The development of the response surface literature occurred largely in association with the study of industrial processes (John [1971]). For this type of study the intent was not so much to explore the entire surface as it was to capture some efficient level of the process surface. The contrast between uses of the technique may be important for descriptive, behavioral, and forecasting models. In these cases it may be necessary to have knowledge of an entire region of the surface and not just a configuration created by a sequence of smaller evolutionary experiments. With such qualifications in mind, the expository results contained in the collection of works edited by Davies [1954] and in the review paper by Hill and Hunter [1966] are recommended as useful references on response surfaces.

Aspects of response surface investigations from the standpoint of sequential analysis and optimal design are developed in a technical but comprehen-
sive review by Chernoff [1972]. As stated earlier, the analytical problems associated with optimal choices of sequential designs are basically problems in control theory. Note that although analytical solutions are practical only for small problems, the framework should still prove useful. In particular, simulation of systems models using this framework provides for viewing the process as simply an approximation to the solution of a complex analytical problem. The framework allows research investigators to focus on useful principles which can be used in simulating systems models, whatever the purpose. This assertion assumes added importance in the context of model tractability and the possibility of developing research strategies using models of models.

EXPERIMENTAL DESIGNS

Numerous choices exist with respect to experimental design. Such choices are of course made in the context of the system purpose, the nature of the experimental problem, and the resources available to the researcher. Given decisions on the factors and factor levels, the assumption on the nature of the response surface and characteristics of interest determine the design (Hill and Hunter [1966]).

First-order experimental designs are used to generate information necessary to fit first-degree (linear) equations. Once the sample information is obtained, such equations may be estimated by standard statistical techniques. That is, by ordinary least squares techniques. These techniques yield parameter estimates with desirable sampling characteristics if estimation problems are assumed to be independent of decision criteria and the experiments are not sequential. Aside from matters concerned with scaling of factors, designs for obtaining the required data are quite easily constructed. This simple design problem follows from the lack of complexity of the assumed response function. Optimal designs are defined as those which for arbitrary residual variances give a minimum value for the trace of the variance-covariance matrix of the estimated coefficients. Examples of optimal designs are 2\(^n-p\) factorials and the Plackett-Burman designs (John [1971]).

Second-order experimental designs are used to generate sample information required to fit second-order polynomial surfaces. As it can be argued that such surfaces approximate more complex ones via Taylor series expansions, higher-order designs are usually not employed. Additional reasons for confining attention to second-order designs are complications introduced by the generation of data necessary to fit higher-order polynomials.

Most designs used in fitting second-order polynomials are symmetric and are scaled to prevent problems associated with units of measure. Examples of such designs are central composites, incomplete factorials, and complete fac-
torials. The applicability of the designs for particular problems is determined by the number of coefficients in the polynomial to be estimated, reliability requirements, and available resources for the experiments (John [1971], Naylor, Burdick, and Sasser [1967], Shechter and Heady [1970]).

"Sequential" experimental designs are simply procedures for conducting sequences of experiments. More ad hoc types of procedures are available in Box [1957] and Box and Hunter [1959]. These designs explore response surfaces by first estimating them for restricted regions and then moving on to estimate other regions on the basis of the information obtained. As J. R. Anderson [1974a] points out, "it is possible to program the automatic location of successive experiments (according to some steepest ascent procedure) and the automatic switching to the intensive search which may be accomplished by simply supplementing the last factorial or triangle design into a composite or hexagonal second-order design, respectively." Gradient and steepest ascent methods are used when such sequences are seeking stationary points in the response surface.

"Policy improvement" experimental designs make use of a number of available policy improvement or optimizing techniques (Emshoff and Sisson [1970]). These techniques often involve sequential designs which begin with an extensive search via simple exploratory experiments arranged so as to converge toward some peak (or valley) of the surface and subsequently to switch to intensive search methods as the optimum is approached. The intensive methods are typically based on second-order response functions while the extensive searches are based on two-level complete factorials (Cochran and Cox [1957]) and "equilateral triangle" designs (Mihram [1972]). For surfaces characterized by irregularities and discontinuities, of course, an exhaustive search will be required (Conlisk and Watts [1969]).

More formal optimizing designs may be based upon methods of optimal control. Dynamic programming solutions appear to be a practical option for designs in smaller problems. For larger problems associated with selecting among various designs at different stages in the decision process, complex error structures, and numerous factors and levels, the only alternative is some type of approximation (Chernoff [1972]).

SIMULATION AND PREPOSTERIOR ANALYSIS

Agricultural economics as an applied discipline is concerned with problems of estimating response functions (usually technical) for use in resource allocation problems. But attempts to obtain more reliable estimates of parameters in themselves present resource allocation problems. As with the more general sequential experiments discussed above, the process of estimating response functions can be viewed as a type of control problem.
The criterion in such problems is implicitly a functional involving within-period gains resulting from the experiment. The structure is given by the nature of the function to be estimated. Control variables are defined for alternative designs, design characteristics, and the extent of experimentation. One difficulty with this framework for response surface estimation involving physical experiments is that the additional information provided by the experimentation is not known until the trials are conducted. If the process is perceived in a Bayesian context (with posterior parameter distributions at one point in time becoming prior distributions in the next), then the revised parameter estimates cannot be known until the posterior distributions are calculated. A promising approach to this problem has been applied by Anderson and Dillon [1968]. They suggest that simulations of a systems model—incorporating what is known of the population and sampling characteristics of the error sources—be employed in numerically examining the problem of optimally allocating resources in response surface research. This process is referred to as preposterior analysis.

Simulations of systems models constructed for this purpose can be useful in providing information on the potential of additional nonsynthetic experimental information. This is especially evident in traditional response surface estimation problems. The concept is also of value in giving guidelines for the design of experiments to estimate the information content of additional sample data. These methods would seem to be applicable to situations in which exploratory research is being conducted for the purpose of developing useful descriptive or behavioral structural models of economic systems, especially where additional data may be required.

Possibilities exist for applications of preposterior analysis in the estimation of response surfaces and the construction of some behavioral and descriptive economic models. However, for research on the structure of economic models, the process may be somewhat more complicated. Complications arise in interpreting simulated data when multiple responses are present (the usual situation) and in establishing the connection between exploratory developments and the underlying theory. Although the problems just mentioned limit its operational value at present, the appeal of the method for systematically utilizing synthetically generated data commends it as an alternative in the application of systems and simulation analysis to agricultural economics research.

Artificial Intelligence and Heuristic Methods

A promising application of simulation concepts is in the development of artificial intelligence. Models utilizing this concept attempt to recreate decision makers' thought and discovery processes, rules of thumb applied to com-
plex real-world systems, intelligent behavior, and effective problem-solving or search methods. They embrace a philosophy for approaching problems heuristically rather than with an organized and definable set of techniques. For many problems not solvable by classic mathematical and statistical models, these methods may be useful. They involve attempts to move toward optimum-seeking solution procedures rather than optimal solutions (Kuehn and Hamburger [1963]).

Artificial intelligence is characterized by Meier, Newell, and Pazer [1969] as “efficient use of the computer to obtain apparently intelligent behavior rather than to attempt to reproduce the step-by-step thought process of a human decision maker.” It is concerned with computer oriented heuristics designed to accomplish such items as search, pattern recognition, and organization planning (Chen [1971], Hare [1967], G. E. Lee [1974]). In a more sophisticated setting it may also include learning and inductive inference.

Although systems models, simulation, and allied techniques were suggested early as means for generating information about economic systems (Clarkson and Simon [1960], Shubik [1960], Simon and Newell [1958]), related heuristic programming and learning constructs have received little attention by agricultural economists. The process of constructing and simulating any model of a system can be viewed loosely as one of developing artificial intelligence. Hence, the observed lack of associated applications is based mainly on the absence of formal consideration of these processes.

The connection of these processes with the theory of learning (Bush and Estes [1959]) is apparent. Heuristic programming and learning theory have been most popular in the study of games (Shubik [1960]). However, they have wide potential applicability in exploratory research associated with the eclectic models employed in agricultural economics. From an economic point of view and in relation to decision models, learning theory is an allocation problem. Hence, applications of heuristic programming and the generation of artificial intelligence fit nicely with the overall adaptive control theory framework. These and the previous comments on the use of synthetically generated data and preposterior analysis present a formal basis on which learning about economic structures and technical response surfaces can proceed. In a more decision oriented context dual control provides a framework within which exploratory models and policies can be developed.

In addition to the areas already mentioned or implied, there are other avenues for possible application of heuristic methods. One is experimental economics (Castro and Weingarten [1970], MacCrimmon and Tota [1969], Naylor [1972], V. L. Smith [1962, 1964], Watts [1969]). Most of these studies are closely connected with the gaming models in which learning and heuristic programming methods found initial application. Few propositions of the tra-
ditional economic theories of individual behavior have been tested in controlled experiments; the few tests available refer mostly to the equilibrating process of simple competitive markets (Kagel et al. [1975]). In comparison with other social sciences where theoretical foundations are not as unified, this is a striking statement. Applications of systems methods in obtaining information about how agents learn and operate within various economic systems would appear to have substantial potential. Simulation methods could be applied advantageously to generate artificial intelligence about the behavior of these economic agents. Some initial efforts in this direction are mentioned in the discussion of gaming literature.

Interpretation

Interpreting results of the simulation of systems models presents substantial problems. More specifically, the amount of data or output generated from simulating large-scale stochastic systems models often gives rise to difficulties. Aside from providing a boon to the paper industry, ill-considered objectives of the research analysis result in the investigator being overwhelmed by a mass of computer output. To be useful the output must be in summarized form (Kleijnen [1972]). Such summaries, however, are likely to be conditioned on the basis of the type of model, the nature of the system, and the purpose of the modeling exercise. As these summaries contain different types of information, it is important that choices of such vehicles be made on an informed basis.

For stochastic and dynamic model representations summary measures of probability distributions over time are frequently required. In this context the “multiple response problem” is often encountered. An outcome may be treated as one of many experiments, each with a single response, or all responses may be combined into a single response. The latter procedure, of course, involves the explicit formulation of a utility or criterion function.

In general, summary measures based on preference function specifications reflect several goals and thus multidimensional structures are relevant. Two general cases of multidimensional preference functions may be distinguished: (1) a scalar valued function providing a single overall utility index may be specified if the various dimensions of utility can be amalgamated in some way; and (2) where amalgamation is not possible (that is, where it is not possible to convert various objectives or goals into a common rubric), but where it is possible to rank goals in order of preference or priority, a lexicographically ordered preference or vector valued function may be specified. In addition, some combination of these two specifications might be employed. Amalgamation procedures require specifying barter terms or trade-offs among different goals. To be sure, for most models a scalar valued preference func-
tion simplifies the computation and presentation of the numerical results. When the goals or arguments are not comparable, or when they cannot be expressed on a quantitative scale, or when the marginal rate of substitution between them is zero (lexicographic orderings), the investigator may resort to a vector valued function for his specification.

Other problems associated with summary measures based on preference functions emanate from their temporal dimensions. In particular, questions related to time preference rates and discount factors are raised. These complications of course are in no way unique to interpretations of simulation results.

DESCRIPTIVE MODELS

Output from simulations of descriptive models may be used to make decisions on further refinements of the model or advanced as an addition to the scientific knowledge on the system being studied. If such outputs are used to revise the descriptive model, then they are best interpreted using some type of objective function governing the revision process. If such an index, amalgamating the various performance measures which might be desired in the descriptive model, can be formed, then the simulations can be systematically viewed. Under these conditions, appropriate summary statistics and relationships to be reported are suggested by the objective or criterion function, model structure, and system.

The presentation of results for evaluating the descriptive models is a more difficult problem. The reason is that any summary of results involves an assumption about how the model is to be used. Ad hoc simulations are the most difficult to summarize and interpret in this regard. Analytical simulations, based on implicit or explicit objectives regarding the potential use of the descriptive model, produce data which are more easily interpreted.

EXPLANATORY MODELS

Explanatory models or behavioral models produce outputs similar to those of descriptive models. Moreover, with the exception of the causality, the problems of interpreting and summarizing simulated output are identical. As with the descriptive models, a clear interpretation of output requires an explicitly stated objective of the modeling exercise. Concern with causality may lead to closer scrutiny of structural coefficients and possible alternatives for structural form. On balance, however, the more ad hoc the simulation process, the more difficult it is to interpret and summarize the outputs.

PREDICTION AND FORECASTING MODELS

Some fairly definite options are available for summarizing and interpreting
output from simulations of forecasting models. First, the fact that the models are being experimented with suggests that more direct statistical procedures are not applicable—probably because of model or system complexity. In this situation results of the simulations should be summarized using the response surface generated by the experimental process. Approximating such a surface with a quadratic expression and designing experiments accordingly gives rise to results which allow more meaningful interpretations than those obtained from ad hoc simulations.

For multiperiod forecasts characteristics of simulated series can be summarized using spectral analysis. Moreover, for some model representations the spectral form can be analytically derived. This includes characterizing the stochastic response of the analytical solution to a system of difference equations by the use of spectral (frequency domain) analysis and indirectly the derivation of the covariance matrix of the internally determined variables (time domain) (Granger and Hatanaka [1964], Naylor, Wertz, and Wonnacott [1969]). In essence, the spectral methods provide a compact description of the second-moment properties for a stochastic version of the model. One of the principal advantages of the spectral analytical approach is that its results are more easily interpreted. As Howrey [1971] points out, “using this method it is possible to derive the stochastic properties directly from the model rather than performing a simulation and then analyzing the results of the simulation.” Furthermore, replications of the stochastic model solutions (as in the case of simulation) are not required and the analytical approach provides a relatively simple means of examining alternative functional forms and parameter estimates. Such characterizations give results which for most model purposes are more informative than collections of ad hoc trials.

DECISION MODELS

Simulations of decision models concerned with regulatory issues are best viewed as policy strategies for the associated control problems. Explicit statements of the criterion functions in such models permit at least numerical approximations of optimal solutions. Results obtained thus have a natural interpretation and can be summarized according to the explicitly defined criterion functions.

For institutional types of decision models the problem of interpreting results is generally more complex. Institutional changes which leave the objective unaltered but involve deletions or additions of constraints can be investigated in a sensitivity analysis framework. Other types of changes contemplated may involve wholesale reorganizations of the system. In these situations objective functions for evaluating institutional designs are less easily identified. As a consequence, the interpretation of results must be cautious. Ex-
exploratory simulations proceeding in an ad hoc or evolutionary manner are frequently the only option in such circumstances.

Applications of Systems Analysis and Simulation

Since their introduction in engineering and military science, systems analysis and simulation have been widely applied to problems arising in many disciplines. In disciplines related to agricultural economics such as management science (Hare [1967]), operations research (Hollingdale [1967]), computer science [Fine and Mclsaac [1966]), social planning [Ingram, Kain, and Ginn [1973]), politics (Coplin [1968]), forestry (Kourtz and O'Reagan [1968]), ecology (Patten [1971], Watt [1966]), and geology (Harbaugh and Bonham-Carter [1970]), the use of these methods has been growing rapidly. It is of course beyond the scope of the present survey to review all of the systems analysis and simulation literature. Only selected applications of systems models and simulation methods in agricultural economics are catalogued and discussed.

At the outset it should be noted that our intention is not to present and discuss a complete list of the published systems work in agricultural economics since World War II. Those interested in a "who's who" or "who done it first" treatment will have to await a survey with different objectives. Our intention in compiling the studies has been to examine a sufficient number of applications to be indicative of common characteristics and future trends. In assembling these studies we have naturally tended to concentrate on those with the widest circulation in the profession. The reader wishing to review systems work in agricultural economics further should consult surveys by J. R. Anderson [1974a] and LaDue and Vincent [1974] for a different perspective on some of the studies we include and for reference to works not incorporated into this discussion.

With the exception of games (which are treated separately because of their extensive use in pedagogical contexts), the applications are grouped and discussed by subject area. Included are models of firms and processes, markets, aggregate systems, and development and natural resource problems. The arrangement of the survey along these lines is designed to serve as a basis for comments on the comparative development of systems methods in the various fields and to provide a reasonably homogenous setting for evaluating modeling attempts. Evaluative comments are closely identified with the earlier general observations on systems and systems analysis. Since reviews of research results in each of the listed subject areas are presented in volumes 1 and 3 of A Survey of Agricultural Economics Literature, our comments are confined to methods. The results facilitated by the use of systems and simula-
tion concepts and inventive applications of associated research methods will be stressed. The general references are summarized in table 1. (Full bibliographical information on these sources is given in the References section at the end of this chapter.)

Games and Gaming

Games as a class of systems models have had an important impact on teaching and extension methods. Whether computerized or not, the wide use of games in these educational activities suggests that useful economic and managerial concepts can be efficiently communicated through participation in a structured decision process (Shubik [1972]). Data resulting from actions of participants in games can in turn be used to form and test various behavioral hypotheses.

HISTORY

Games as related to systems and simulation owe their beginnings to the development of similar constructs for investigating various war strategies. The historical basis for the more modern developments with gaming has been nicely documented by Longworth [1970]. War games apparently attracted the attention of business people in about 1956 when the American Management Association sponsored a group to develop a management game called "Monopologs" (Longworth [1970], Bellman, Clark, et al. [1957]). These efforts generated substantial interest in the use of management games as teaching or learning devices during the late 1950s and early 1960s (Greenlaw, Herron, and Rawdon [1962]).

Management games have been described (Longworth [1970]) as falling into three rather broadly defined categories—the total enterprise games, which include the early management games as well as their much more complex descendants; the specialized or industry games, which relate to a specific industry; and the functional games.

The early interests of agricultural economists in games are typically identified with the names of Babb [1964], Eisgruber [1964], and Hutton [1966]. As these initial efforts were strongly influenced by the business management games, it is not surprising that they were concerned with farm management. In fact, as Garoian [1967] points out, nonagricultural business management games were utilized in some agricultural economic classes before the development of agricultural games. An earlier application, but with a slightly different orientation, involved production control in a cheese plant (Glickstein et al. [1962]). Subsequent efforts have addressed the more complex problems encountered in group interactions of participants as well as more comprehen-
sive enterprise models. An extensive survey of these efforts is contained in Longworth [1970]. A less detailed recent discussion of games and simulation can be found in LaDue and Vincent [1974].

DISTINGUISHING CHARACTERISTICS

Models concerned with games and gaming fit within our conceptual framework. From the standpoint of participants, games are decision problems. Participants are typically provided with some information, perhaps incomplete, about the game and are asked to play by making decisions according to some specified criterion. Playing the game then requires participants to operate within a prescribed decision framework. The flexibility of the decision framework and the facility for allowing participants to refine their perception of the decision problem through structured or unstructured learning processes determines the complexity of the game.

If games are utilized as a pedagogical device, then it is assumed that playing will result in increased proficiency. The increase in proficiency may, of course, come about as a consequence of an increase in the participant's modeling skills and analytical ability or through the accumulation of factual information about the structure of the system (Cohen and Rehnman [1961]). If games are utilized as a research tool, then records of individual play are utilized as a basis for examining the behavioral hypotheses or the outcome of the game itself. In the first case the means by which various types of economic agents make decisions may be investigated. The second case involves the types of studies typically identified with the subject of experimental economics (Castro and Weingarten [1970], Frahm and Schrader [1970], Frazier, Narrie, and Rodgers [1970], Naylor [1972], V. L. Smith [1964], Whan and Richardson [1969]).

ILLUSTRATIVE FORM

Structures of models used for games are standard. The models include a mechanism for presenting the participant with options. The characteristics associated with the options include a payoff, restrictions on future choices, and in some cases implications for the participant's relationship to other players. As previously indicated, information available to players on the characteristics of the options and even the number of options usually includes a degree of uncertainty. Players make a sequence of choices under prescribed rules of play. The outcomes of these choice sequences are then evaluated in terms of some criteria specified either relative to the player's behavior or a standard identified with an optimal strategy given some general behavioral objective.
SURVEY

The characteristics of twenty-five gaming models are summarized in table 2. Reviewing the table permits some general conclusions on the focus of research in this area. Fourteen of the games involve farm management problems, four are concerned with the management of retail and processing functions, five are marketing models which include participant interaction, and two are vehicles for generating data to be used in behavioral research. If the surveyed works are representative, then it would seem safe to conclude that most applications of gaming concepts include individual decision makers and micro-economic units. Aggregate models and group decision making—except in some marketing applications—have not been the subject of gaming applications.

The first computerized farm management game, developed by Eisgruber [1965], was based on a model of a central Indiana mixed enterprise firm. This game was employed as a prototype for the development of a farm management game and a poultry farm management game (Fuller [1968], Fuller, Ruggles, and Yergian [1968]). Four other farm management games are those developed by Faris, Wildermuth, and Pratt [1966], Hutton [1966], Kay [1973], and Vincent [1970b]. The Hutton game has been widely employed in teaching farm business analysis to high school and adult students (Curtis [1968]).

The characteristics of the remaining models vary widely. The recent models, with the exception of those used entirely for behavioral research, are computerized. Computerization of games simply makes them more manageable and thus permits more complex structures and elaborate stochastic components. As the discussion of the prototype indicates, most are multistage processes and thus involve a time component in the selection of strategies. In general, the games used are akin to those developed in management or, more generally, in the business disciplines.

Other noteworthy references for games and gaming models are Bentz and Williams [1965], Hutton and Hinman [1968], LaDue and Vincent [1974], Longworth [1969], F. J. Smith and Miles [1967], Von Neumann and Morgenstern [1944], Walker and Halbrook [1965], and Wehrly [1969].

SUMMARY AND EVALUATION

Applications of gaming concepts in agricultural economics have been generally successful. Over the past ten years they have assumed a prominent role in undergraduate and extension teaching activities. Babb and French [1963] were apparently the first to recognize the potential value of management games for these activities. Intuitively, important benefits are anticipated if
firm decision makers are allowed to experiment with a simulation model rather than with its real-world counterpart.

There are some limitations of the existing models or (to take the positive view) some promising options for further model development in comparatively unexplored areas of application. First, regarding the development of gaming models, there is limited evidence of efforts to corroborate the games with the decision situations for which the participants are being trained. Although considerable efforts have been made to construct realistic games (that is, to make the model valid for the system studied), little formal information is available which might be utilized to corroborate them with the underlying systems. Advances in this direction would involve more systematic procedures for structure specification and parameter estimation.

With regard to simulation or play, gaming exercises could become more useful as learning tools if more attention were given to the processes by which participants arrive at strategies. Many of the games appear to do little more than force participants to formulate objectives for play. The exercise could be enhanced if more careful consideration were given to the processes by which optimal strategies are determined. One such game has been introduced by Eisgruber [1965]. A related area of unexploited potential involves the possibility for integrating this facet of games with the Von Neumann and Morgenstern [1944] results on utility maximization and decision making under uncertainty. Ideas which might be developed in this context have been suggested by Shubik [1960] and Wagner [1958].

Second, little attention has been devoted to problems of determining the educational value of games. Except for the works by Babb [1964], Babb and Eisgruber [1966], Curtis [1968], Hammond, Strain, and Baumel [1966], and McKenney [1962], all of which are rather surprising in the inconclusiveness of their findings, formal results on this subject are unavailable. In general, the studies indicate that games or gaming exercises are productive; however, there is little economic analysis of the costs and benefits of games in the different types of teaching and extension activities (Dolbear, Attiyeh, and Brainerd [1968]). If games are to be used as teaching devices, then more careful evaluations of their effectiveness in different teaching and extension contexts would be useful in the design of new games and in promoting more informed use of existing games. Interesting attempts to evaluate the educational value of games in classroom situations are currently finding an outlet in the Journal of Economic Education. A particularly desirable feature of these results is that they are based on data gathered under explicit experimental controls (Weidenaar [1972]).

Finally, it seems that the potential of games as a tool in behavioral re-
search could be more fully exploited (Babb, Leslie, and Slyke [1966]). The studies by V. L. Smith [1964] and Frahm and Schrader [1970] are indicative of models which can be developed for these purposes. Experimental tests of propositions from the theory and specific ideas on the firm and market operation appear quite useful. Examples of the latter include tests of competing hypotheses concerning the behavior of cooperative managers and members, operators in farm growth models, market actions, and the degree of uncertainty as to actions of competitors.

Firm and Process

Systems models of firms and processes are of the decision type. Typically they are concerned with the problem of providing information to be utilized for improved resource allocation within the decision units modeled. The majority of these models involve firm decision situations and are designed to produce results for dealing with problems of uncertainty, growth and adjustment, and adaptation. These problems present substantial conceptual and computational difficulties for the more traditional neoclassical and activity analysis models of the firm. Application of the systems approach has given rise to a number of ambitious modeling efforts in this area.

HISTORY

Many of the early firm and process model applications outside of agricultural economics may be found in such journals as *Management Science*, *Operations Research*, *Behavioral Science*, and the *Journal of the Association of Computing Machinery*. Engineering applications of process models are frequently found in *Simulation*, and business applications have appeared in *Simulation and Games*. Within economics, systems analysis and simulation assumed increased importance with the introduction of the behavioral theory of the firm paradigm (Cyert and Marsh [1963]). This paradigm appears to be particularly useful when restricted to the analysis of firm behavior; it was developed, in part, by the use of simulation. Moreover, it often involves a number of disciplines in addition to economics. For example, Bonini [1964] has introduced accounting, organization theory, and behavioral science into a model representation of firm behavior. Similarly, Cyert and March [1963] have employed behavioral science, psychology, sociology, and organization theory along with economics. In a process model context such multidisciplinary approaches have been most frequently applied to the design of communication and data handling systems (Beged-Dov [1967], Vazsonyi [1965]).

The interests of agricultural economists in firm and process models are obviously longstanding. Applications of systems concepts and simulation
methods in this context, however, are of recent origin. In fact, the earliest of the studies surveyed was published in 1962 (Glickstein et al. [1962]). Hence, the literature on applications of systems concepts and simulation methods to firm and process models involves more recent studies. Because of this, and, as we mentioned earlier, because subject area surveys have been commissioned in these fields by the American Agricultural Economics Association, we shall not dwell on the history of firm and process models prior to the development of systems applications.

**DISTINGUISHING CHARACTERISTICS**

Firm and process models are typically stochastic and dynamic and involve some nonlinearities. The stochastic aspects of these models are a particularly important feature and usually emanate from exogenous weather conditions or prices. In a management context the resulting risk and uncertainty are dealt with nicely by simulation. These methods do not require that the forecast density function of the decision parameters satisfy any particular shape or mathematical equation, and thus they allow the researcher to employ the complete range of data pertaining for each parameter (Clarke [1968]). This analytical complexity is introduced as a result of attempts to model the intricacies of the firm or process. As a consequence of such complexity, direct solution methods—even for the simpler objective functions—are usually not feasible. Hence, models are simulated for policy choices, for sensitivity to parametric and structural change, and the like. Results of the simulations are evaluated using objective functions or are simply presented as outcomes from selected courses of action.

**ILLUSTRATIVE FORM**

As noted earlier, firm models are studied largely for decision purposes. It will be clear from the survey that applications have been mainly concerned with regulatory decisions. Though facilitating studies of more elaborate problems, systems and simulation concepts have not changed the context of the research questions in these models.

In the case of process models a typical form would address the design and analysis of a facility layout. The principal advantage of simulation in evaluating facility layouts is that the actual cost of the physical facility is avoided. Examples of these forms include warehouse locations for large-scale multi-plant firms (Kuehn [1962]) and iterative models for determining the optimal location of a firm's facilities (Armour and Buffa [1963]). Other typical forms of process models include job-shop sequencing and such farm processes as harvesting and storage.
Although not mutually exclusive, the studies listed in table 2 can be classified according to whether they are process models, management and farm planning models, or growth models.

Process models involve specific types of producing and marketing activities or plants over which a firm has control. These studies are typified by models of the sort developed by Brooks [1962], Cloud, Frick, and Andrews [1968], Doster [1970], Glickstein et al. [1962], Smith and Parks [1967], Sorensen and Gilheany [1970], and Wright and Dent [1969]. Of these, the work by Glickstein et al. [1962] is noteworthy because it preceded many of the others and influenced subsequent investigations. Recent models are more elaborate in their complexity and in their sources of uncertainty. This uncertainty often emanates from stochastic weather conditions. Most farm process models have addressed the operation of the soil-plant-water system (Nelson and Schuck [1974]). Subcomponents of this system have been incorporated in models of dryland cropping (Blackie and Schneeberger [1971], Dumsday [1971]), grazing (Goodall [1971], Jones and Brockington [1971], Wright [1970]), and irrigated cropping (Phillips [1969]). Harvesting and storage processes have also been examined. For the former, efforts have been concentrated on the efficient selection of machinery (Cloud, Frick, and Andrews [1968], Donaldson and Webster [1968], Jose, Christensen, and Fuller [1971], Sorensen and Gilheany [1970], van Kampen [1971]). In the case of storage processes inventory analysis has been employed to determine efficient quantities of fodder to harvest or purchase (Morley and Graham [1971]). The models employed in these studies have comparatively simple objectives, which include minimizing costs, maximizing returns over costs, and mean variance types of efficiency criteria.

The growth models may be thought of as extensions of budgeting studies applied in farm planning. Perhaps because of the preoccupation with farm management and planning in traditional agricultural economics departments, these models are numerous. Studies of this type include those by R. L. Anderson [1968], Donaldson and Webster [1968], Eidman, Dean, and Carter [1967], Halter and Dean [1965], Hinman and Hutton [1970], Hutton [1966], Vincent [1970a, 1970b], and Zusman and Amiad [1965]. These and other studies include examination of crop farming (Dumsday [1971], Flinn [1971], van Kampen [1971], Zusman and Amiad [1965]), mixed farming (Hutton and Hinman [1968]), beef (Halter and Dean [1965], Trebeck [1971]), sheep (J. R. Anderson [1971], Hughes [1973], Johnston [1973], Wright [1970], Wright and Dent [1969]), pigs (Dent [1971]), dairy (Hutton [1966]), and turkeys (Eidman, Dean, and Carter [1967]). Roughly
one-half of these investigations focused on the choice of production methods. The remaining one-half are concerned not only with the choice of production level but also with marketing and investment strategies. The analytical purposes of these studies might be characterized as investigating the temporal aspects of product sales (Eidman, Dean, and Carter [1967]), input management rules (Dent [1971]), economics of soil conservation (Dumsday [1971]), economics of amalgamation (Johnston [1973]), and spatial diversification (Trebeck [1971]). In most of these applications we find examples of individual firms planning in dynamic and stochastic environments. The advantage of the systems approach for stochastic planning problems lies in its flexibility. Numerous production activities can be considered along with many types of strategies for combining them.

Four of the planning models merit special comment. Each represents an innovation which would appear to be promising for future planning work. The first study, by Eidman, Dean, and Carter [1967], combines simulation and Bayesian decision theory to evaluate uncertainty in commercial turkey production contracting. Incorporating a Bayesian formulation of the decision problem provided a way of dealing systematically with decisions encountered in farm planning. The second study, by Halter and Dean [1965], examines management policies under conditions of both weather and price uncertainty. Observed historical data were used to estimate probability distributions, which were in turn sampled for range conditions in the specified range feedlot problem. By using this means of summarizing the characteristics of the historical environmental conditions, the authors were able to evaluate the numerical results from the models within a related probabilistic framework.

The third study, by Zusman and Amiad [1965], is noteworthy for the methods applied in examining the response surface of the firm model and, correspondingly, for the way the model was simulated. Here again, weather uncertainty and cropping patterns were explicitly recognized with respect to the response surface. The methods used preceded the current interest in experimental design and response surface identification (Naylor [1971]). Also, analytical criteria and the method of steepest ascent were used as bases for choosing sequences of policy simulations. That is, choices of policy variables were made using information available on the response surface in the maximizing framework suggested by the decision problem. Choices of policies then amounted to a numerical type of gradient method optimizing procedure.

Finally, important efforts to develop general firm planning models have been made by Hutton and Hinman. In the first model, developed by Hutton [1966], dairy herd characteristics were emphasized. The planning horizon for this model is variable and the model may be simulated stochastically. The
The principal limitations of this model are its heavy technical input requirements and the exclusion of all enterprises except for the dairy herd. More recently, Hutton and Hinman [1968] developed a model designed to process data for a wide range of farm planning situations. Stochastic price and purchase options, sale of capital items, and input and product price trends are admitted. The specified production functions are linear and independent. All activities in this model are defined by the user, and specific applications are available in Hinman and Hutton [1970, 1971].

Turning to the studies on firm growth, a limited number of references are summarized in table 3 and by Armstrong, Connor, and Strickland [1970], Harle [1968], and Patrick and Eisgruber [1968]. Other firm growth investigations involving the application of simulation methods include Boehlje and Eisgruber [1972], Charlton [1972], Dalton [1971], Eisgruber and Lee [1971], Hinman and Hutton [1971], S. R. Johnson, Tefertiller, and Moore [1967], Lins [1969], and Walker and Martin [1966]. The authors of these studies were among the first to argue for the use of simulation in farm growth research. Much of the subsequent work on simulation and farm growth models has been undertaken by Eisgruber and his associates at Purdue University. In Patrick and Eisgruber [1968] simulation was employed to deal with multiple firm goals; in Eisgruber and Lee [1971], and particularly in Boehlje and Eisgruber [1972], a search routine was constructed to select superior alternatives. The routine, which combined the Monte Carlo method with a "hill climbing" procedure, is based in part upon the earlier work of Thompson [1970]. Decision rules characterizing this routine assign probabilities to various activities which are subsequently revised depending upon the income generated when alternative combinations of activities are chosen. Sequential combinations depend upon the updated probabilities associated with each activity.

The construction of the tabular survey for firm growth models was particularly difficult. As a result of the comprehensive and difficult investment and decision problems involved in the study of firm growth, many of the applied studies in this area could be classified as being based on systems and simulation concepts. Most models are highly specialized and require numerical approaches for solution. Lastly, the study of firm growth in agricultural economics represents an interesting phenomenon in applied work. The firm growth work probably began in response to the increases observed in farm size, and at first it was largely descriptive. As these early efforts were refined, attempts to reconcile them with more conventional theories emerged. This trend is evident in a series of papers from a Great Plains Regional Com-
mittee conference held in 1965 (Great Plains Agricultural Council [1967]). Because of its flexibility the systems approach was of considerable value in facilitating applied work and in stimulating theoretical interest in this area.

Other references relating to firm and process models that should be noted are Albach [1967], Burt [1968], Flinn [1971], Great Plains Agricultural Council [1967], and Tanago [1973].

SUMMARY AND EVALUATION

Of the firm and process models surveyed, approximately 75 percent are dynamic, 60 percent are stochastic, 70 percent are nonlinear, almost all involve passive validation, roughly 90 percent have a decision orientation, and, finally, about 50 percent are both stochastic and nonlinear.

In reviewing the studies in table 3 as they relate to the general framework for systems analysis and simulation presented earlier, we find them deficient in a number of respects. Work to validate or corroborate models with systems has been limited. The quality of the results obtained from some modeling efforts suggests that a substantial amount of informal validation work was done. However, there is little mention of the application of the more formal and systematic tests discussed earlier. Since the purpose of these models is the generation of information to be employed in regulating or controlling the related systems, it appears that more explicit and systematic attempts to validate the models would have been advantageous.

A second area of potential for improving models and results is in the design of the simulation experiments. In a number of the planning, process, and growth models the subject of investigation is some type of response surface (perhaps the value of a profit function based on options pertaining to regulatory variables). The models are so complex (in terms of nonlinearities and stochastic components) that the study of response surfaces without considerable attention to experimental design may provide misleading information. As these models become more realistic and complex, the problem of identifying, with a high degree of reliability, the response surfaces of interest is likely to increase in importance.

Our last observation concerns the objective functions implicitly or explicitly employed. Because the models are stochastic, it is necessary to apply various kinds of indexing schemes to accommodate the stochastic arguments. The Bayesian and related expected utility approaches represent a promising development in this regard. The work of Eidman, Dean, and Carter [1967] represents a positive step in this direction. As these ideas are introduced, it will be necessary to take advantage of their full benefits in terms of possibili-
ties for analytical solutions (Burt [1968]). In this connection the analytical simulation methods used by Zusman and Amiad [1965] will also become more commonplace in future work with process and firm models.

Market or Industry Models

Market or industry models typically involve the study of structures governing the movement of commodities from producers to consumers. Many of these studies are of distribution channel systems. Others are concerned with single market systems for particular products. Research objectives are associated with improved understanding of the behavior of such systems and their evolution over time or with improving the decision processes of the components comprising the system. Behavioral market and industry models often involve attempts to improve the understanding of interaction and feedback relationships among various components. Decision model applications are frequently concerned with the evaluation of alternative marketing policies.

HISTORY

Agricultural applications in this area have been strongly influenced by the earlier studies of Cohen [1960] and Balderston and Hoggatt [1962]. Both studies were concerned with distribution systems. The Cohen model, consisting of over six equations, involved an attempt to explain the behavior of various elements in the vertical structure of the hide and leather industry. Balderston and Hoggatt examined price and sales determination in the West Coast lumber industry. Major decisions about prices, order levels, and production levels for each of the components (hide dealers, leather tanners, shoe manufacturers, shoe retailers, and final buyers) were included in the Cohen model. The Balderston and Hoggatt model was less concerned with the vertical structure of the lumber industry than with the critical role played by lumber brokers in matching potential sellers (timber growers) and potential buyers (lumber retailers).

Both of these models were highly complex, including large numbers of decision modules and linkages incorporating nonlinear and stochastic features. In this regard the Balderston and Hoggatt model offers an interesting contrast to the work of Cohen. Balderston and Hoggatt began with a set of postulates regarding the economic behavior of different market participants (rather than with a set of historical series) and utilized artificial data to determine how the specified market operated under different conditions. They concentrate on attempting to understand the properties of a hypothetical model. Thus, their simulations are essentially synthetic in nature. The principal features of the model include limited information, varying information costs, preference orderings, and localized search. A very similar approach has been employed
by Preston and Collins [1966]. Cohen, however, operated with real-world data, and, since his constructed model was too complex to solve directly, he resorted to a simulation of it over time. Although the results were not particularly favorable, this model nevertheless remains a prototype for many of the subsequent econometric simulation efforts in the area of vertical market structures. A common feature of the Balderston and Hoggatt [1962] and Cohen [1960] studies is the high degree of specialization achieved for the market and industry studied. This feature and the modeling and simulation techniques which evolved for studying systems at this level of abstraction are reflected in a number of agricultural economics applications.

Earlier attempts to model the conceptual apparatus of economic theory and the linkages between individuals and groups (Clarkson and Simon [1960], Orcutt [1960], Orcutt et al. [1961]) have led to much in the way of subsequent applications. These attempts might be regarded as a combination of the sorts of applications found in the firm and process category and those appearing in this section. Orcutt's enterprising approach of aggregating individual consumer and producer behavior is fraught with data and computational difficulties. Simulation of mixed-level models involving both individual and aggregate demand and supply relationships is particularly difficult. As Manderscheid and Nelson [1969] have pointed out, such models include variables which are exogenous at one level and endogenous at another (for example, price at the firm and industry levels). Hence, to achieve consistency between the two levels, feedback effects must be recognized and iterative simulations are usually required. These iterative simulations involve resimulation of the individual or micro units if the aggregate industry level variables are not consistent with the magnitudes of these variables when treated exogenously at the micro level.

Although less comprehensive, the Balderston and Hoggatt work on the lumber industry may be viewed in the same spirit as the Orcutt approach. Other less ambitious investigations have concentrated on only the demand side of particular industries or markets. These include imperfectly competitive market models (Amstutz [1967]) along with a number of advertising and marketing applications (Kotler and Schultz [1970]). Agricultural economics applications have typically concentrated on the supply side. For example, Bender [1966] and Duewer and Maki [1966] have analyzed the meat industrial structure by simulating representative firms, their interactions, and meat product markets.

DISTINGUISHING CHARACTERISTICS

The characteristics of these models peculiar to the study of market processes include (1) the heavy use of separate decision components and the re-
lated decomposability for studying particular aspects of the systems, (2) the variation in theoretical, empirical, and intuitive content, and (3) the high degree of complexity resulting from provisions for the interaction of components and the low level of abstraction. Effective utilization of these models requires substantial familiarity with the intricacies of the market or process being studied. Model forms generally evolve from provisional structures through interaction with industry personnel and internal comparisons of decomposed decision unit performance. This is the reason an institutional knowledge of the industry is important as a prerequisite for model construction and evaluation of simulations. This observation is not surprising since existing economic theories of market organization are sufficient only to give useful guidelines for studies which represent minimal abstractions from the true systems.

ILLUSTRATIVE FORM

The major components of market or industry models are usually associated with one or more of the following sectors: consumer, retailer, wholesaler, transportation, producer, inventory, and foreign trade. The structural composition of these models is often specified so that interactions between components can be treated recursively. This characteristic typically is rationalized on the basis of information flow within the industry and is important in making the problem analytically tractable. Representations of these components include lagged effects and interacting variables as well as non-linear relationships. Departures from linearity, however, are not substantial. Although most of the constructed models contain stochastic elements, only seven of the twenty-four studies surveyed recognize stochastic components when simulation experiments are performed. The majority of the models were investigated only in a deterministic or expected value form.

The observed model complexities are generally consistent with the typical behavioral orientation of such studies. As previously noted, the objective of such modeling exercises is to distill information on the causal characteristics of the system. It is therefore quite consistent for researchers to use the uncertainty principle or, more formally, the adaptive control framework in coming to a selected form which meets the objectives of the investigation and satisfies the constraints imposed by the resources available for the study. Owing to the prominence of these evolutionary methods, an illustrative form of the model is difficult to isolate. The research decision process by which these models evolve often has a definite structure, but the models are as different as the markets or industries studied. In fact, the implication of this observation for problems of generalizing results is also a major concern with
firm and process models. We can therefore cite common characteristics but not a general form.

SURVEY

As firm and process models are highly individualistic, our survey is restricted to a discussion of several representative studies. The studies selected for detailed examination include Candler and Cartwright [1969], Crom and Maki [1965a], Naylor, Wallace, and Sasser [1967], Raulerson and Langham [1970], Vernon, Rives, and Naylor [1969]. Each one has interesting features vis-à-vis the market or industry studied and their connection to the earlier works of Cohen and Balderston and Hoggatt.

The Raulerson and Langham study [1970] was concerned with the Florida frozen concentrated orange juice industry. The authors applied Forrester's industrial dynamics approach [1961] along with the associated DYNAMO simulation language. The model used consisted of 137 equations representing features of growers, processors, retailers, and consumers. Parameters entering many of these equations were specified on an a priori or subjective basis. Conscious attempts were made to isolate the information feedback characteristics and the related amplifications and delays presumed to exist in the industrial system being modeled. Validation of the constructed model was accomplished by graphically comparing simulated and actual sample values for selected variables. Tracking and turning points were emphasized as measures of model performance.

A major objective of the Raulerson and Langham model was to examine alternative policies. The policies included (1) free market or no intervention, (2) product allocation to two separate markets, (3) removal of productive trees, (4) curtailment of new tree plantings, and (5) various combinations of options (2) through (4).

The Crom and Maki model [1965a] is perhaps most closely related to Cohen's work [1960]. The authors' purpose was to construct an econometric model to explain behavior in the beef and pork sectors of the United States economy. The model is recursive except for beef and pork prices, which are specified to be jointly determined. The unknown parameters of the model are estimated from historical data. Ad hoc simulations of a nonstochastic version of the model are used as a basis for behavioral conclusions. The procedures employed are bothersome in terms of our earlier comments on validation. More specifically, Crom and Maki [1965a] revised equational specifications (changing length of time lags, coefficients, and limiting values) after examining historical comparisons of sample and simulated values. Many of these changes were conditioned upon particular values of endogenous variables de-
terminated by such graphical comparisons. In other words, behavioral relations were modified until a representation was achieved which could reproduce the historical (sample) period with sufficient accuracy. Unfortunately, the conditional changes were introduced ex post and only on the basis of the graphical comparisons—no other justification or explanation is provided. This approach is an obvious violation of classical statistical methods, Bayesian methods, and other inference procedures. The reported $R^2$'s and significance tests (not reported) on the estimated coefficients have no real meaning. The chief danger of this approach is that the constructed model will not isolate to an acceptable degree the systematic and enduring characteristics of the system under examination.

The Naylor, Wallace, and Sasser model [1967] and the Vernon, Rives, and Naylor model [1969] are similar to the models by Cohen [1960] and Crom and Maki [1965a]. Both models were constructed around the distributional components of a single industry. Time series data were utilized to estimate unknown parameters of models specified in recursive form. The Vernon, Rives, and Naylor model [1969] recognizes a monopolistic structure on the selling side and an oligopsonistic structure on the buying side of the tobacco leaf market. This model consists of nineteen equations, seven behavioral and twelve identities. Policy variables such as acreage allotments, support prices, and soil bank plans are incorporated as exogenous factors to the model, but no policy or decision examinations are provided. Marketing factors including effects of advertising expenditures on cigarette consumption were excluded from the analysis. Validation was attempted by using Cohen's process simulation approach [1960] and graphical comparisons of the resulting simulated and sample values.

The Naylor, Wallace, and Sasser model [1967] of the textile industry consists of nine behavioral equations. The basic orientation of the model is behavioral. Process simulation analysis is employed over the historical record, no policy alternatives are examined, and experimental design methods are not utilized. A principal aspect of this study involves the application of alternative validation techniques. Three techniques (graphical, spectral, and total variance analysis) are utilized to compare simulation results with observed data. The spectral analysis approach was found to be the most useful. One of the principal advantages of this approach is its compact description of the second-moment properties of stochastic models. In contrast to the spectral simulation approach a spectral analysis approach is also possible. In nonlinear stochastic models this approach may be referred to as the spectral analytical simulation method since approximations to the nonlinearities present in model must be utilized (Rausser and Johnson [1975]).
The Candler and Cartwright study [1969] is substantially different from those just outlined. In terms of response surfaces it is somewhat similar to Zusman and Amiad [1965] except that the objective is to estimate the performance surface throughout the space corresponding to selected ranges of the variables or factors. Relationships are advanced to capture the effects of specific assumptions regarding these variables on the resulting outcomes. The problem was to derive more general and explicit functional relationships between decision variables, structural parameters, and performance statistics. With these functions outcomes or performance measures can be estimated directly without recourse to additional simulations. The study is not one of direct optimization, but rather it focuses on estimation of the objective function components that are associated with particular levels of the decision and exogenous variables. The use of experimental design procedures was emphasized in the simulation of the model. Second order polynomials were utilized to approximate the performance surfaces. The relative weights attached to multiple performance statistics were not specified. Instead, separate functions were estimated for each performance statistic that might enter the ultimate objective function. The suggested procedures were applied to a budgetary study of the potential for increased sheep production in New Zealand.

Finally, the vast amount of work on simulating a number of subsectors within the textile industry and the commodity analysis completed at the Harvard Business School should be at least briefly mentioned. For the textile industry, the computer simulation model developed by Zymelman [1965] serves as the principal illustrative example. The commodity analysis work is basically descriptive; most of these investigations employ a systems taxonomy but do not involve any attempt at quantitative synthesis. This approach might be characterized as a systems analytical description of a commodity or industry (B. C. French [1974]) and involves efforts to identify structural changes and desirable adjustments. Applications of this approach include Goldberg’s analysis of wheat, soybeans, and oranges [1968]; Arthur, Houck, and Beckford’s analysis of the banana industry [1968]; Marion and Arthur’s analysis of the broiler industry [1973]; and Morrissy’s work on fruits and vegetables [1974]. Although this descriptive work represents an obvious requisite for the development of analytical models, none of these applications has explicitly addressed the synthesis and design stages of the systems modeling approach.

Among the other important studies using market and industry models are the following: Agarwala [1971], Armbruster et al. [1972], Barnum [1971], Bell, Henderson, and Perkins [1972], Benson [1969], Benson, Bender, and Lofourcade [1972], Crom [1967], Crom and Maki [1965b], Desai [1968],
Approximately 80 percent of the models surveyed in this section are dynamic, only 30 percent are simulated stochastically, roughly 75 percent are nonlinear, and about 30 percent are both stochastic and nonlinear; less than 10 percent are actively validated. Most of these applications have a behavioral model purpose. It is also interesting to note that these applications fall into one of two general classes—either the Orcutt mixed-level microaggregate [1960] or the strictly aggregate industry or market-level class. The models by Balderston and Hoggatt [1962] and Duewer and Maki [1966] serve as examples of the former class, and the models by Cohen [1960] and Vernon, Rives, and Naylor [1969] are illustrative examples of the latter class. Most of the strictly aggregate class of market or industry models involve process simulations of econometric representations. Such simulations utilize generated endogenous values of the past periods to determine, in part, the current period simulated values. In other words given the value of lagged endogenous variables for periods t-1, t-2, etc., the model computes values for the internally determined variables for period t.\(^9\) Owing to their highly specialized nature these models are difficult to evaluate. Presumably all worked acceptably for the purposes intended.

A number of things can be learned from reading the accounts of the exercises and the types of results which were obtained. First, it is apparent that response function and associated experimental designs employed by Candler and Cartwright [1969] along with the experimental design techniques discussed here can be used to advantage in testing the behavioral propositions implicit in these models and in the validation exercises. Second, the estimation procedures employed could be more systematized by employing the parameter estimation methods discussed earlier. The combination of prior information, whether subjective or from other studies, with data using these techniques should be useful in improving the reliability of the parameter estimates. Third, it would appear that future studies could benefit from a more explicit recognition of the adaptive decision problem involved in model construction. The adaptive model construction framework suggested here should result in the development of better models and a reduction in their individualistic content.

Aggregate Models

Simulation studies of aggregate systems include those related to national
economic levels and to agriculture at a sectoral level. Although a survey of national models is not within the scope of this paper, it would be unfortunate not to mention the large number of models available and the importance of simulation and systems methods in corroborating them with the system and in applying them to forecasting and decision problems. For those interested in becoming acquainted with this work we recommend a survey paper by Fromm and Klein [1973] and a recent collection of simulation studies of the United States economy appearing in a volume edited by Klein and Burmeister [1976] as useful starting points in the literature.

Aggregate models of the agricultural sector tend to have less econometric content than the national models. Because of data limitations, concerns with detailed behavioral relationships and associated interactions, and the incidence of particular policies, these models tend to be complex and accordingly to involve research approaches closely related to those discussed in connection with firm and process models.

HISTORY

Studies of policy questions for various commodity sectors have been of major interest to agricultural economists since the 1930s (Heady and Tweeten [1963]). In general, the development of quantitative methods to analyze problems posed in comparing and evaluating alternative governmental policies applied to the agricultural sector have reflected those used to solve other types of problems. The first attempt to construct a detailed representation of the United States agricultural sector appears to be the model developed by Cromarty [1958]. The principal emphasis in the Cromarty analysis was on construction; the purpose of developing the model was to measure the major relationships within the agricultural sector and between agriculture and the remainder of the economy. The model was not used for forecasting purposes, policy formation, or intercommodity analysis. Similar representations of the United States agricultural sector may be found in Fox [1963] and Evans [1969]. The Evans study, although not frequently referenced in the agricultural economic literature, was one of the first attempts (along with Tyner and Tweeten [1968]) to simulate an econometric representation of the United States agricultural sector. Using ad hoc simulations, Evans examined the sensitivity of his model representation to increases in personal disposal income, consumer nonfood prices, productivity within the beef and hog sectors, and soybean meal exports, and he evaluated such policies as increased acreage restrictions for feedgrain and increased milk and soybean price supports. The approach was much the same as that used in the research efforts devoted to the construction and simulation of macroeconometric models (Fromm and Klein [1973], Fromm and Taubman [1968], Holt [1965]).
In recent years still more aggregated simulations have been performed in attempts to forecast future world population, income, natural resource stocks, and food production (Forrester [1971], Meadows, Meadows, Randers, and Behrens [1972]). These representations are strong departures from the earlier simulations of macro and agricultural econometric sector models. The data base for such futuristic world models is virtually nil, and the assumptions and methods employed are highly questionable. Accordingly this work has encountered energetic and caustic criticism (Cole et al. [1973]).

Turning back to specific aggregate models in agricultural economics, we find a large number of studies on various commodities and agricultural sectors. These studies employ quite different model construction and policy evaluation techniques. Some are more closely linked to systems and simulation concepts, and others emanate from more traditional econometric origins. The studies examined in this section are largely associated with the former group. However, it will be clear from subsequent as well as previous comments that the distinction between these two sets of methods is artificial.

DISTINGUISHING CHARACTERISTICS

Aggregate models are typically constructed for decision and forecasting purposes. For decision problems the object is to evaluate the implications of alternative policies. Although the models have a strong decision orientation, only the study by Shechter and Heady [1970] operated with an explicit criterion function. The criterion function employed by these authors is only partially explicit, expressed in terms of four independent criteria for which neither weights, satisfactory levels, nor orderings were specified. Hence, there was no attempt to resolve conflicts between farm income and, say, government costs; instead, weight or ordering assignments to various goals are reserved by these authors for policy makers.

Other studies have relied on implicit objective functions (reflected by the specified performance variables and the particular policies examined). Most of these aggregate models are dynamic and nonhistorical and incorporate feedback mechanisms in a recursive fashion. The models are generally nonlinear, but not in a way which presents substantial problems for derivation of the reduced forms or the generation of the endogenous variables from the structural form. Although the question of corroboration is discussed in connection with each of the models, few formal tests or descriptive measures are advanced in attempts to validate the representations.

ILLUSTRATIVE FORM

Models in this classification, although diverse, can be reasonably characterized as systems representing one or more components of developed agricul-
tural sectors. They are typically highly aggregative and incorporate many simplifying specifications (for example, Cobb-Douglas aggregate production functions), and almost all of the models refer to the United States agricultural sector. The exception in table 4 is the United Kingdom food and agricultural model constructed by McFarquhar and Evans [1971]. Most are constructed to examine quantitative effects of alternative governmental policies (price supports, governmental inventory purchases, acreage allotments and diversion programs, government payments). The agricultural sector systems examined are usually decomposed into a number of components or subsystems and a building-block approach is employed in model construction. Although the major components of these models differ, they are generally concerned with supply and demand for various products, in some cases with agricultural input or resource levels, and with linkages to the nonagricultural economy. Other aggregate components are often included to generate internally determined factors such as farm income. These are recursive to and derived from the basic components.

SURVEY

The works of Edwards and De Pass [1971], Lin and Heady [1971], McFarquhar and Evans [1971], Ray and Heady [1972], Shechter [1972], and Tyner [1967] are selected for specific discussion. These studies are viewed as representative of the approaches to aggregate systems modeling. The Tyner study [1967] forms the basis for the results reported in Tyner and Tweeten and is similar in nature and scope to the Lin and Heady model [1971]. Both models are recursive, with the equations estimated by means of ordinary or autoregressive least squares. Moreover, both examine via ad hoc simulation experiments effects of the elimination of all governmental programs and alternative assumptions about the rate of technological change. The output or commodity components of the two models are represented by a single aggregate production function, supply (or sales), and a demand set of equations.

The Ray and Heady model [1972] utilizes a categorization of variables similar to the groupings employed by Tyner and Tweeten [1968] but is less aggregative, containing submodels for livestock, feedgrain, wheat, soybeans, cotton, and tobacco. All of these submodels are recursively related, and they include resource use, production, price, final demand, and gross receipt components. The model is passively validated; no attempt is made to recognize the underlying stochastic distributions in the various simulation runs, and the simulations performed are not formally designed. The ad hoc and historical policy simulations examined include the removal of government price and income support programs, increases in input prices, and 10-percent increases in corn and wheat support prices. The apparent deficiencies of the construct-
ed model are the weak linkages between the various commodity submodels and, in turn, their linkages with the national economy.

The model constructed for the United Kingdom by McFarquhar and Evans [1971] is similar to the preceding models, involving far more detail than those by Tyner and Tweeten [1968] and Lin and Heady [1971] and roughly the same level of detail as the model by Ray and Heady [1972]. Three components of the model—final demand, intermediate and primary demands, and supply—are treated recursively and each component is simulated separately. The first component, the final demand, encompasses twenty-seven food products and one nonfood product. All equations giving these quantities are estimated by ordinary least squares. The intermediate primary demand component is composed of thirty-nine agricultural and nonagricultural input products related to products consumed as food. This component is constructed as an input-output model assuming constant technology. The supply component is treated as four subsystems based on commodities: wheat, barley, cattle, and sheep. Most of the equations for these subsystems are dynamic, involving simple adjustment mechanisms or geometric lags, and are estimated by stepwise least squares. The model is employed to examine the potential effects of the entry of the United Kingdom into the European Economic Community (EEC) along with associated price and import policies.

The model by Edwards and De Pass [1971] is different from those just discussed and is quite similar to one reported by Edwards [1970]. The concern is with domestic rural development—that is, with the growth and distribution of population, income, and employment across rural and urban sectors. Accordingly, the model contains rural and urban components. Owing to difficulties of isolating these two major components on an aggregate basis for the United States, four alternative and basically arbitrary delineations were examined. Simulated results for these four delineations were found to be invariant with respect to general conclusions regarding future prospects. Urban and rural, income, employment, and population growth equations are developed on a similar exponential basis. A net migration equation between the two components is also specified. Parameters of the structure were estimated by trial and error, the criterion being the reproduction of 1970 data from the 1960 data for population, income, and employment. Sensitivity analysis was utilized to investigate various parameter changes as well as alternative policies. Various targets for population, income, and employment were specified. Promising policy actions proved to be associated with an expansion of job opportunities. More jobs in rural areas and, to a lesser extent, increased labor productivity appeared to have a greater impact than either reductions in outmigration or rural population birth rate decreases.

One of the more interesting applications of aggregate models is the Shechter
study [1972] (for a condensed version of this model, see Shechter and Heady [1970]). In some respects it proceeds along the lines of the investigations found in Candler and Cartwright [1969] and Zusman and Amiad [1965]. The model is based on both micro components (individual farms in northern and southern Iowa) and macro components (aggregate output variables of all farms). A response surface analysis approach to simulation experiments is emphasized. The experimental design is partial factorial, and optimal search procedures take place for univariate responses. For each of the four response variables and associated surfaces relative maximum or minimum points were discovered. An independent examination of each variable revealed that rather large improvements could be made in the design of the system. Validation of the underlying micro and macro components representing the real system involved a simple historical comparison of observed and explained values for a few of the systems outputs.

Other simulation methods which might be classified as aggregate models include the works of Agarwala [1971] and Reutlinger [1970a]. The Agarwala model analyzes various stabilization policies for agricultural markets. Reutlinger’s study stands in contrast to the remaining models surveyed in this section. Reutlinger explicitly recognizes stochastic aspects and uncertainty associated with attempts to evaluate buffer stocks of grain programs at national levels.

Other aggregate models that should be noted are those by Blase, MacMillan, and Tung [1973], Chen [1970], Lins [1973], and Schaller [1968].

SUMMARY AND EVALUATION

Most of the models surveyed in this section are dynamic and nonlinear and have decision or policy orientations. However, there are indeed few of these models, perhaps too few, that are stochastically simulated or actively validated. Most of these studies totally neglect uncertainty of the behavioral components modeled; if stochastic components are incorporated in various representations (particularly the econometric specifications), they too are neglected in the simulation of the constructed models. We fully expect that this will be corrected in future efforts to model and examine various policies at sectoral levels.

It should be clear from the comments in connection with the survey that the study by Shechter and Heady [1970] is the most advanced in terms of applications of systems concepts and simulation methods. The recognition of response surface estimation problems and the application of appropriate experimental designs form an important step in the development of useful results from aggregative systems models. As evidence of this assumption we need only compare the other studies with the one by Shechter and Heady.
The final commentary on the studies concerns the use of validation methods. In reflecting on the recent experience with national models, we wish to emphasize our agreement with Cooper [1972], when he suggests that careful corroborative analysis is extremely important for the policy and forecasting functions of aggregate models.

Future research with regard to the aggregate class of models surveyed in this section will most likely be even more ambitious than those currently available. Given present perceptions of world problems, these simulations will involve such variables as population, incomes, resource stocks, food production, and demand. As J. R. Anderson [1974a] has asserted, "agricultural economists will ultimately become very involved in at least the improved specification of rates of technological change in food and fiber production, off-farm migration rates, income elasticities for farm products, and so on, at world levels."

Development Models

Problems of economic development also lend themselves to the systems analysis approach. They are typically eclectic and highly specialized to the country under examination. These characteristics are presumably due to different institutions, to a wide diversity of agricultural industries, to large differences in the resource bases, and to the exploratory nature of the analyses. The eclectic nature of these systems models is illustrated by the inclusion of demographic and sociological components. The specialization is based not only on the particular traits of the agricultural industry and related institutions but also on the diverse political structures and restrictions with regard to potential policy variables and objectives. The exploratory aspects of these models derive from their strong policy orientation and from an absence of fundamental types of behavioral and technical relationships and data which might be employed to identify them.

HISTORY

Applications of systems concepts and simulation methods to development problems are largely outgrowths of the Nigerian consortium (Manetsch, Hayenga, et al. [1971]). The ambitious Nigerian model developed at Michigan State University had its origins (both data requirements and conceptualization) in early applications of systems concepts by Holland [1962, 1968]. The first of these (the pioneering work) examined problems of economic development and foreign trade policy for Venezuela. This was closely followed by Gillespie and Holland [1963], an exploratory development planning model with special reference to India. In 1967 Kresge constructed a similar general simulation model to be used for policy evaluations in Pakistan. These stud-
ies represent initial applications of systems concepts and simulation methods to development planning, although they are nonagricultural, it is clear that they have influenced subsequent efforts in the construction of development models. In addition to the Michigan State work on Nigeria and Korea (Manetsch [1974]), the models include those constructed by Foster and Yost [1969] for Uganda, by Mathis [1969] and Billingsley and Norvell [1971] for the Dominican Republic, Singh and Day [1972] for the Indian Punjab, and Simpson and Billingsley [1973] for Paraguay.

An overview of historical efforts in this field also suggests that development models may be viewed simply as transfers of methods applied to similar problems in developed countries. For example, the work of Halter and Miller [1966] had a marked influence on the models constructed at Michigan State University for Nigeria and Korea. Other applications such as Day and Singh [1971], Singh and Day [1972], and Taylor [1969] provide further support for this claim.

DISTINGUISHING CHARACTERISTICS

Because of the unavailability of data and other problems just mentioned, systems models constructed for development studies have some easily identifiable characteristics. They generally make substantial use of component and decomposition possibilities. Although levels of component autonomy along with levels of aggregation are different among models, both are much in evidence. The value of the components approach in these studies is based upon team research project possibilities, as typified by the Nigerian study (Manetsch, Hayenga, et al. [1971]), and associated advantages for dealing with the problems created by a lack of information.

Another important characteristic of these models relates to their theoretical content. With a few exceptions (notably the models by Day and Singh [1971] and Singh and Day [1972]) the models are aggregative—that is, specified at industry, regional, or sectoral levels. As a consequence, the models are often descriptive, with more emphasis on the structure of particular economies than on established theories. As indicated earlier this characteristic of the models adds substantially to the validation problems. The data are limited in quantity and quality. Aspects of this latter problem are further complicated by the multitude of alternative hypotheses associated with the specified structural models.

ILLUSTRATIVE FORM

The forms of development models are highly variable. Some are aggregate and thus similar to the type discussed in the preceding section. Others are market or industry models and therefore resemble those mentioned in the
section on Market or Industry Models. A third class consists of micro models which have very close ties with theories of the firm and individual behavior. Special types of micro models are concerned with the diffusion of new techniques among farmers in traditional sectors. A rural sociological approach to this problem has been advanced by Carroll [1968], and a microeconomic approach that simulates farmers' perceptions and their changes by Bayesian analysis (probabilities are revised as experience accumulates) and then aggregates individual technique switching rates to community adoption rates is presented by O'Mara [1971]. The common aspect of these models is of course that they concentrate on the dynamic features of the less developed economic systems studied.

SURVEY

The sector economy models surveyed are those by Halter, Hayenga, and Manetsch [1970], Manetsch [1974], Manetsch, Hayenga, et al. [1971], and Taylor [1969]. Along with these models we might also have included those by Billingsley and Norvell [1971] and Foster and Yost [1969], which are not sectoral or economy models but which incorporate similar methods of analysis. Both models have demographic components; the Billingsley and Norvell model is concerned with evaluating alternative government fertility policies, and the Foster and Yost model is concerned chiefly with the relationship between growth, education, and income in less developed economies.

Sector models identified with Michigan State University [1973] are by Halter, Hayenga and Manetsch [1970], Manetsch, Hayenga, et al. [1971], and Manetsch [1974]. These studies report on massive systems modeling efforts in Nigeria and Korea. The models employed in the studies are complex and extensive by comparison to others surveyed. Each uses advantageously the components concepts just mentioned. The methods of model formulation, estimation, and simulation employed in the studies are not innovative. Encouraging aspects of the endeavors involve possibilities for adapting the software for work with other economies (Manetsch [1974]) and the fact that the work has generated considerable interest among policy makers. It is also interesting to note that these efforts were developed for clearly defined clients—namely, government planners. The research investigators on this project were able to interact with their clients and to obtain their support in acquiring the information and data to construct the model representation. This effort was, of course, costly; development and operation costs associated with the Nigerian model were approximately $300,000 (Manetsch, Hayenga, et al. [1971]).

In the remaining sectoral model Taylor [1969] presents a departure from the larger and more comprehensive efforts just discussed. It is a systems mod-
el tied quite closely to the Domar theory of economic growth for developed countries. It is estimated by standard econometric techniques and is evaluated by means of a highly structured format.

The regional model listed in table 6 is by Day and Singh [1971] (see also Singh and Day [1972]). This development model is noteworthy in two respects. First, it corresponds to a micro firm model and as such has stronger theoretical underpinnings than the other development models. The model is designed to study the change from traditional to commercial agriculture in the Punjab. It is recursive, with a number of feedback alternatives involving changes in the adaptation of technology, market prices, and so on. The incorporation of a lexicographic ordering of objectives seems to represent a very promising possibility for models applied in the development context. A second noteworthy aspect of this study is the set of validation procedures employed. Not only do the authors include a discussion and application of formal validation procedures, but the procedures themselves are novel in the sense that they involve the use of information theoretic concepts (Day and Singh [1971]).

Models for industries include studies by Aldabe and Rijckegehm [1966], Lehker and Manetsch [1971], Manetsch and Lenghner [1971], Manetsch, Ramos, and Lenchner [1968], Miller and Halter [1973], and Roberts and Kresge [1968]. Aside from institutional and information problems which are typical in development studies, these works are similar to the industry studies reported in the market model survey. The models are typically descriptive, without well-defined criterion functions, and are designed for studying or forecasting influences of policy actions on industry output, price, and the like.

Other references using development models include G. L. Johnson [1970], Rausser [1973], and Thorbecke [1971].

SUMMARY AND EVALUATION

Most of the development models have decision or policy purposes and, as expected, all are dynamic. Approximately three-quarters of these models are also nonlinear. However, few of the models were simulated stochastically, and only approximately one-third were actively validated.

With the exception of the model by Day and Singh [1971], the systems studies are themselves underdeveloped with respect to the design of policy experiments and response surface examination. (For a more detailed discussion of the possibilities along these lines, see Rausser and Johnson [1975].) The lack of advancement regarding method can be explained in part by the fact that the studies were highly exploratory and frequently performed under time constraints and with inadequate information bases. It is in these areas
that development studies are likely to be improved. The work already done in development modeling suggests a high payoff for refining the methods used in these studies.

Although methodological difficulties confronted in the construction of development models will continue to represent formidable obstacles (Norvell [1972]) and much justified skepticism exists concerning the value of such exercises, it appears that funding sources for such efforts will provide renewed and augmented support. A project under way by Heady and his associates in Thailand, employing a large number of people, is one illustrative example justifying this expectation. It is hoped that such work will result not only in improved policy selections by the governments of developing countries but also in improved methods of data gathering, modeling, and simulation. In particular, this would be an ideal area in which to consider questions of proper data basis and, in fact, what data should be collected by the public sector (Rausser [1973]). Unfortunately, as yet such questions have not been explicitly addressed.

Resource Models

In this area, as with gaming models, the modern applications of systems concepts and simulation methods have much historical significance. However, in contrast to the importance of simulation in the early development of gaming models, the emphasis in the resource literature was initially on the concept of a system. Systems concepts, growing out of the physical aspects of the problems studied and the engineering literature, found a very natural application in studies of resource problems.

HISTORY

The evolution of modern systems concepts as related to water resource problems has been well documented by Hufschmidt [1963]. Apparently the notion of systems especially in the context of river basin planning has been clearly understood since about 1900. Evidence of the long familiarity of engineers with the concept may be found in still earlier writings (Ellet [1853]). The concept in an operational setting first found extensive application in the integrated program initiated under the Tennessee Valley Authority in 1933. By 1950 it had been employed at operational policy levels in structuring approaches to water resource problems (President's Water Resource Policy Commission [1950]).

Modern treatments of water resource systems based on quantitative models began at about the time that electronic computers emerged as a research tool. As the systems framework was largely in place, the application of simulation tools to resource models came rapidly. Interdisciplinary water re-
sources planning was initiated at Harvard in 1955, and by 1962 the highly influential volume, *Design of Water-Resource Systems*, was published (Maass et al. [1962]). This volume and the studies associated with it have had an important impact not only on water resources research but on applications of modern systems concepts and simulation methods in other fields of economics as well as other areas of the social and physical sciences.

**DISTINGUISHING CHARACTERISTICS**

Systems and simulation applications to natural resource and regional development problems often involve the public sector. As Kain and Meyer [1968] have noted, simulation is particularly useful when evaluating "public investments characterized by important externalities, broad social objectives and durable installations." When we add to these features the importance of uncertainty, technological change, research and development strategies, and the sequential aspects of natural resource decision making, computer simulation becomes an even more appealing tool (Rausser and Dean [1971a, 1971b]).

In a mechanistic sense models of resource systems are generally dynamic and nonlinear. Some nonlinearities are fairly substantial, including those involving artificial time-counter relationships. Dynamic structures of these models are often characterized by lagged, internally determined, and conditioning variables and are represented by a system of difference equations. Approximately 50 percent of the models are simulated in stochastic form. Most stochastic simulations are limited, however, in the sense that only additive stochastic (disturbance) elements are recognized—that is, only first moments of sampling distributions of the structural parameter estimates are used. They also include a large number of the stochastic simulations developed for the physical models representing hydrologic phenomena.

Simulation experiments for this group of models are more sophisticated than for the models previously surveyed. Various partial and complete factorial designs have been employed to examine response surface questions. Some designs also involve optimum seeking methods. Validation procedures however, are less precise. Only eight of the studies went beyond graphical comparisons of sample or historical and simulated values of selected output variables. The predictive properties of the models were typically neglected in corroborating them with the systems in question.

**ILLUSTRATIVE FORM**

Table 7 contains a tabular survey of applications of simulation methods to agriculturally related resource problems. It is by no means an exhaustive list, but simply one intended to be representative of the available works involving
natural resource and regional economic systems. Most of this work has focused on river basin systems or watershed systems. Hence, the major components of the models frequently include information on the various flood, demographic, transportation and use sectors, reservoirs for irrigated crop production, and the like. These components are often treated recursively and there is typically a substantial amount of temporal interaction and feedback among them.

Benefit-cost criteria usually provide the basis for evaluating alternative policy decisions in these systems. Decision models comprise about one-half of studies surveyed. Most of the others are behavioral models and are largely descriptive. The behavioral models are principally concerned with the development of physical relationships such as those involving natural hydrologic phenomena (Maass et al. [1962]).

SURVEY

The models specified in Halter and Miller [1966], Hufschmidt and Fiering [1966], Hamilton et al. [1969], Rausser, Willis, and Frick [1972], Rausser and Willis [1976], Jacoby [1967], Dudley and Burt [1973], and V. T. Chow and Kareliotis [1970] are viewed as representative of this group and selected for further discussion. The first three models concern river basin systems. The Halter and Miller model represents an early application of industrial dynamics to water resource development projects. The proposed projects of the Halter and Miller model were dam construction and channel improvements in the Calapooia River Basin. The benefits of dam construction and channel improvements included irrigation, flood control, fishing, and drainage. A particularly interesting aspect of this model was the treatment of the temporal distribution for hydrologic flows. These flows were generated internally in the model by a random number generator process. Considerable care was taken in attempts to assure that the simulated hydrologic data conformed to historical flows. The experimental design used for the decision problem was reasonably simple with no indication of how the combination of project size and operating rules was selected and evaluated.

The Hufschmidt and Fiering model [1966] is more general than the one advanced by Halter and Miller. The Hufschmidt and Fiering study presents the steps and procedures for a simulation program including aspects related to collecting and organizing hydrologic and economic data. These procedures were applied to the Delaware River basin and to its subsystem, the Lehigh River basin. An interesting development for synthesizing hydrologic events is provided. Pollution is considered along with abatement costs. Three criteria were employed to validate the models. For decision applications, economic consequences (benefit and costs) associated with design variables and outputs
were evaluated under several assumed interest rates, static and dynamic investment patterns, and discounting methods. An explicit criterion function was specified—namely, the present value of expected net benefits along with the variance of these benefits. A few basic plans were investigated and, from the knowledge accumulated, improvements were made upon the basic plans and the search continued. However, no specific search procedure was developed.

The third river basin study conducted by Hamilton et al. [1969] is of a more regional nature than either of the other two. As a case study of systems simulation applied to regional economic and river systems modeling, it should prove of value for some years to come. A useful aspect of this study is the inclusion of an appendix containing a short discourse on the management of a multidisciplinary research project. The principal objective of the work was to advance the state of the systems simulation art for regional analysis, particularly where social and technological factors form an integral part of the system under examination. The illustrative model (Susquehanna River basin) is composed of three major components that describe the demographic, employment, and water supply characteristics of nine subregions comprising the river basin.

Important features of the Hamilton systems model are (1) the inclusion of demographic and economic components in a single model; (2) the explicit application of economic and engineering concepts to regional water resource problems; (3) dynamic aspects in the form of feedbacks and lagged variables within the various components as well as between components; and (4) the ability of the model to facilitate sensitivity analysis. One of the interesting results of the simulation analysis was the indication that water shortages emanate not from scarcity of the water resource itself but from current water treatment, storage, and distribution systems.

Turning from the river basin models, we must note the recent studies by Rausser, Willis, and Frick [1972] and Rausser and Willis [1976], which were advanced in an attempt to determine the proper level of public subsidies for water desalting plants, the investment levels and sequencing of various water source developments, and the allocation of water across different use sectors. The bases for the public subsidies are the external benefits which result from "learning"—in this case, the accumulation of knowledge on desalting techniques. Experience gained in the construction and operation of a particular desalting plant is presumed to lead to more efficient production for future plants. In a dynamic context costs depend not only upon the current level of production but also upon cumulative experience.

A "learning by doing" model provides the basis for the nonlinear and dynamic learning functions (Rausser, Willis, and Frick [1972] estimated by clas-
sical and Bayesian methods. For the Bayesian estimates, two alternative families of prior probability density functions were utilized. The first was based on the learning experience of nondesalting industries and the second on sample desalting costs of foreign plants. Based in part upon these estimates, a joint probability distribution including external learning benefits was specified. Since it was not possible to derive the marginal density function for benefits analytically, computer simulation experiments were employed. Given the approximated external benefit distributions, appropriate levels of public (state and federal) subsidies under alternative assumptions were derived. The computed subsidies enter a multiple source decision framework comprised of two major components, one for sequencing investments in water supply facilities and the other for allocating water supplied under uncertainty across regions and use sectors. Since the "curse of dimensionality" precluded an analytical solution, these two components along with the subsidy component were solved separately, and iterative simulation was employed to achieve consistency among the three components (Rausser and Willis [1976]).

The model developed by Jacoby [1967] emphasizes alternative investment and operating decisions for electric power plants in West Pakistan. The potential investments in generation facilities for each of several electric power markets are analyzed. Each plan was constrained to satisfy predetermined power demands, and the associated temporal patterns of operating costs were specified. The computer simulation model generates outputs of various plants, ranges of fuel prices, transmission constraints for each year, the distribution of foreign exchange rates, and the distribution of opportunity costs of capital. The latter information is particularly important given the multi-purpose nature of hydroelectric and irrigation developments in the regions investigated. Experimental designs employed in this simulation analysis involved both multistage techniques and partial factorial designs. On the basis of a single basic demand projection several plans were tested, some of which were eliminated from further analysis. This initial analysis provided a new set of combinations to be investigated. Unfortunately, no real attempt was made to validate the constructed model.

The Dudley and Burt [1973] model was intended to determine the "best" area size for irrigation in conjunction with a reservoir of given capacity. The specified criterion function involves a twenty-year planning horizon, net revenue derived from irrigated cropland, net revenue derived from dryland crops, and fixed costs of capital items. The actual effects of varying acreages were determined by simulating over a twenty-year period for both stochastic demand and supply. The acreage for which the largest value of the criterion function was obtained was regarded as optimal for irrigation development.
Sensitivity analysis was employed in an attempt to determine how the selected acreage should be altered under varying opportunity costs. Opportunity costs were allowed to vary from 50 to 150 percent of original estimates. Quadratic functions (for each level of opportunity costs) relating net revenue to irrigable acreages were also estimated, and penalties for employing sub-optimal acreages were computed. No attempt to verify the constructed model is advanced, and the experimental design is simple.

A number of models related to the above efforts have been constructed to analyze rural and regional development problems. An illustrative example of a rural development model is the work of Doeksen and Schreiner [1972], which was utilized to analyze state investments in agricultural processing. Following the model developed by Hamilton et al. [1969], Fullerton and Prescott [1975] constructed a regional development planning model for Iowa. This model provides a formal basis for achieving spatial and temporal consistency between the state economy and its smaller components (counties and cities). Systems concepts and simulation have also been applied to natural wildlife resources. For example, several interesting simulation experiments conducted to improve the management of a deer herd are discussed by F. M. Anderson et al. [1971].

Recent applications which follow an earlier suggestion by Dorfman [1965] to combine the use of analytical optimization and simulation methods are the models developed by Jacoby and Loucks [1972] and Dudley and Burt [1973]. The first study involves construction of a river basin planning model in which the number of available development opportunities is extremely large. To analyze the resulting framework in a tractable fashion, Jacoby and Loucks employ analytical optimization models to screen the set of possible plans and select a smaller number for detailed simulation analysis. The stochastic aspects of the problem are explicitly recognized in this study and in the Dudley and Burt model. The latter model, following the earlier work of Dudley [1972], uses a simulation model to compute state variable transition probabilities, which in turn are utilized in a stochastic dynamic programming model to determine (1) the optimal intertemporal water application rates, (2) the optimal abandonment of irrigated acreage for the remainder of the season, and (3) the optimal acreage to plant for potential irrigation at the beginning of the season.

As previously indicated, several of the studies represented in table 7 refer to physical models concerned with hydrologic phenomena. The model by V. T. Chow and Kareliotis [1970] is representative of these studies. This hydrologic model was formulated in the context of a watershed system and was applied to the upper Sangamon River basin. The model input is rainfall and the output is runoff and evapotranspiration. Runoff is composed of three
stochastic components—groundwater storage, total rainfall, and total losses. Three alternative models for these processes are compared and evaluated. These models are basically a moving average, a sum of harmonics, and an autoregressive specification. In selecting among models the non-nested nature of the hypotheses (or the disparate families of hypotheses) represented by the alternative model representations was not recognized. Instead the selection was based upon correlogram and spectral analysis. All three runoff components were found to exhibit correlograms oscillating without any indication of dampening. Along with the power spectrum of the sample data revealing significant peaks for six-month and annual periods, this resulted in the selection of a combined sum of harmonics and autoregressive time series model representation. No explicit attempt was made to validate this mode, feedback effects were notably lacking, and experimental designs were not utilized in simulating runoff processes.


SUMMARY AND EVALUATION

The resource systems models are generally more advanced relative to the other survey application areas, particularly in terms of their detail and the methods employed in using simulation for decision analysis. However, they might be characterized as deficient in terms of model validation and theoretical foundations. Owing to their complexity, this is not an unexpected result. In general, the early and substantive work done with systems in connection with water resources research and the sustained record of incorporating new developments are reflected in the quality of the models and the promising results obtained.

A trend of recent vintage and one that we hope will continue and experience further growth is explicit recognition of risk and uncertainty. In addition to the studies surveyed here various models have been advanced to explore the impact of risk by stochastically simulating alternative project performance. Illustrative applications of these efforts may be found in the occasional staff paper series of the World Bank (for example, Pouliquen [1970] and Reutlinger [1970]). Applications of these methods along with other approaches to uncertainty in a water resource context are treated in Rausser and Dean [1971a, 1971b].
Critique and Appraisal

In the previous sections we have discussed and documented the value of systems concepts and simulation in agricultural economics. The impact of the modern development of systems analysis and simulation techniques, however, is apparent. New and more ambitious approaches to problems posed in the context of existing paradigms and exploratory work with less confined constructs have been stimulated by the development of systems and simulation methods. In fact, the vitality associated with the renaissance in research and teaching processes which has occurred as a result of the incorporation of these methods may represent their most important contribution. Grappling with the difficulties presented by applications of this highly flexible approach and attempting to refine it should continue to provide the profession with a basis for a stream of useful results.

Our survey of both methods and empirical applications indicates that the value of systems analysis and simulation can be more fully exploited if the two processes are themselves more systematically employed. Moreover, the appropriate framework to be utilized as a basis for systematizing the processes of model construction and use involves concepts of adaptive control. Given the usual stated objectives of model construction and the dynamic, searching processes implied by the use of systems concepts and simulation, adaptive control procedures present a natural framework for systematizing the sequences of decisions required to implement the approach. The fact that the most useful applications and the most promising developments of method can be shown to embody these concepts should suffice to underscore their current and potential importance for the processes of systems analysis and simulation.

One of the much emphasized attributes of systems and simulation methods relates to the use of the approach as a substitute for more expensive or larger-scale physical experiments. Within the adaptive control framework problems resulting from attempts to formulate and investigate such models have a natural criterion function—that is, the criterion function is to maximize the information content of the results less the costs of complexity, given physical, institutional, time, and budget constraints. Policy or control variables for problems formulated in this context, however, are less apparent. At present they would seem to be discrete types of choices such as methods of parameter estimation, complexity of the model, scale of prototype, choices of paradigm, verification procedures, and the like. Choices of control variables would of course vary with the problem being studied and the purpose of the modeling exercise.
An interesting method for handling problems of this type is the preposterior analysis suggested by J. R. Anderson and Dillon [1968]. For crop response function estimation, this approach provides the researcher with a means of effectively positioning actual physical experiments. As a consequence, model complexity and the cost of the physical experimentation can be reduced. In this exercise the control variables relate to the extent of preposterior analysis and the choices of physical experiments based on such information. Although not fully exploiting the sequential nature of such problems, the structured approach advanced by these authors has a wide area of potential application. Surfaces generated by criterion functions in decision models, predictive performance functions, and measures of appropriate behavior characterization can obviously be viewed in a response framework. Accordingly, the associated response functions can be explored, at least conceptually, using methods of preposterior analysis.

Model construction is an obvious activity in which an adaptive framework can be advantageously applied. Currently, a major limitation associated with the flexibility of systems analysis and simulation, particularly in the context of exploratory modeling, is the close identity of the model with the researcher. Adaptive control procedures employed in moving sequentially from provisional to final models of systems can be quite helpful in depersonalizing research results. In this manner the adaptive modeling approach can aid in making research results verifiable by other investigators. Concerns associated with this aspect of systems models and results of simulations (Department of Defense [1972], Rausser and Johnson [1975]) are likely to provide strong incentives for developing models on the basis of more structured processes.

A related development concerns the process of verifying models. Our discussion of the applications indicates that with some notable exceptions (for example, Singh and Day [1972]) agricultural economists have been somewhat lax in corroborating systems models. Methods of accomplishing this task are rapidly being developed (Rausser and Johnson [1975]). As these advances represent an additional means of evaluating comparative models, they should find wider application as systems analysis and simulation become more commonly applied in agricultural economics research. Alternative model verification procedures are of course choices in the context of the adaptive model construction problem.

These advances in verification techniques have in large part been made possible by the advancement of structured rationalizations for the process of estimating or specializing systems models for particular situations. In this regard, the debate surrounding the Forrester contention [1961] that sample data or past data on the system are not useful in constructing models has been grossly unproductive. Instead of searching for an estimation method sufficiently gen-
eral to incorporate the Forrester argument, many researchers have apparently chosen instead to reject statistical and econometric approaches to model construction. The unfortunate result was and is that the associated models have little generality. If one cannot establish that the parameters of a systems model are at least partially estimated on a sampling basis, then the foundations for generalizing the results and verifying the model simply are not present. In view of these problems, the mixed estimation methods (Theil [1971]), the Bayesian methods (Zellner [1971]), and the associated generalizations to the sequential processes involved in model construction (Leamer [1970]) represent most promising developments.

Applications of the systems models are also likely to benefit from more highly systematized simulations. The shopworn and increasingly suspect argument that systems analysis presents a method for analyzing problems without a criterion function will soon lose its acceptance. If viewed with sufficient abstraction, it is clear that all models (since they are readily admitted to be purposeful) involve some type of criterion function (Rausser and Freebairn [1974a, 1974b]). This being the case, experiments with systems models can be much improved. Recognition and incorporation of the criterion function can provide a basis for conducting experiments with the systems models which are considerably more informative. In this regard, the works of Zusman and Amiad [1965], Shechter and Heady [1970], and Jacoby and Loucks [1972] represent examples of methods of model application which are likely to prevail in future work.

The same observations apply of course to behavioral and predictive models. That is, given a criterion for the research exercise, experimental designs can be advantageously applied to enhance the value of simulated results. Again, the emphasis is on a more structured approach to the application of the models. Applications of these methods are likely to produce results of the type developed by Candler and Cartwright [1969]. Incentives for explicitly identifying criterion functions are also likely to occur as a result of difficulties arising in summarizing and presenting outcomes of simulations. Without some method of summarizing these experiments the output from model simulations can quickly become unmanageable. Summarizing, however, if it is to be useful and to represent the outcomes of the experiments accurately, requires the specification of a criterion function. Hence, full exploitation of systems models conditioned upon the various time and budget constraints and the presentation of results in the most meaningful fashion are among the compelling arguments in favor of complete specification of the model including the criterion function.

Given the preceding comments concerning the structuring of model development and applications, one might counter by suggesting that past ap-
plications of the systems approach were justified in proceeding in an unsyste-
matized manner because they were heuristic. Here again, however, there are
well-established arguments for structuring research efforts more carefully. In
fact, the major points associated with the gathering of artificial intelligence
and heuristic modeling (Kuehn and Hamburger [1963], Meier, Newell, and
Pater [1969]) are themselves based on systematized search techniques. Their
implications for learning about systems through systems analysis and simula-
tion are therefore consistent with the methods which have identified the
adaptive control framework with promising developments.

What are we to infer from these observations on promising developments
and their identification with adaptive control processes? Obviously, they do
not imply that everyone should rush out and purchase a copy of the latest
text on adaptive control. Research and teaching activities based on systems
concepts and simulation, although effectively viewed within the control
framework, present problems which are not currently mathematically trac-
table. Hence, it is principally the conceptual basis of control rather than
actual solutions to adaptive control problems which is advanced here as pro-
viding a basis on which systems analysis and simulation can be systematized.

If the argued relationships between modern control theory and systems
analysis are correct, then we may anticipate substantial adjustments in both
our research and teaching efforts. Contrary to rather widely held opinions,
the advent of systems and simulation concepts has not freed us from our pre-
vious preoccupation with economic theory and quantitative methods. That is,
instead of allowing researchers to circumvent some more traditional areas of
training in quantitative methods and theory, the more advanced aspects of
systems and simulation analysis require even stronger backgrounds in these
areas. It is becoming increasingly clear that a knowledge of computer pro-
gramming or some special simulation language is not a license for conducting
effective research in agricultural economics. Statistical and theoretical ques-
tions raised by the application of systems models are of such magnitude that
research produced by mechanical applications of the approach is likely to be
of little general interest.

The implications of the foregoing observations for the training of graduate
and undergraduate students and for our extension tasks are reasonably clear.
The flexibility of the systems method has suggested applications which take
us away from the familiar confines of neoclassical theory, classical statistical
methods, and some of our closely held methodological paradigms. As applica-
tions of systems models become more systematized, it seems inevitable that
additional study of optimization theory (in dynamic and stochastic contexts)
and Bayesian and sequential statistical methods will become more common-
place. Moreover, our conceptions of the process of learning and generating
new knowledge are quite likely to be severed from the positive doctrines which dominated thinking along these lines in the 1950s and 1960s.

The advent of the predicted changes should be most encouraging. It foretells the eventual merger of our theories of individual behavior with data or empirical evidence and methods of estimation. It would be unfortunate not to acknowledge the debt of such advancements to the concepts of systems and systems analysis. The questions raised by the development and application of systems concepts and simulation methods have had a substantial impact in stimulating interest in refining techniques of estimation and in extending the theory. At the same time our discussion has indicated that systems analysis of economic problems as currently applied in the discipline is itself in for some rather substantial alterations.

Tables of General References and Surveys

Table 1 contains a list of the general references on systems simulation analysis and simulation cited in the text. In the remaining six tables the references on the various kinds of applications are summarized: table 2, gaming and related models; table 3, firm and process models; table 4, market and industry models; table 5, aggregate models; table 6, economic development models; table 7, natural resource models. In these tables the studies are identified by the names of the authors and the year of publication, and the modeled situation, the objectives, and the decision variables are described briefly. The reported characteristics in table 2 include the time dimension and whether or not the model is multistage, competitive, open or closed, computerized, or stochastic. The reported characteristics in tables 3-7 include type of model, type of simulation, computer language, validation procedures, and information on whether the model is dynamic, stochastic, or nonlinear.

Most of the characteristics listed in tables 2-7 are self-explanatory. The three characteristics which may require elaboration are validation, type of simulation, and the competitive versus noncompetitive classification for the gaming models. The terms used to describe the validation process are active and passive. All researchers are of course concerned with corroborating model representations with systems and, in fact, are probably implicitly doing so at all stages of the construction process. Such implicit corroborative activities are described in the tables as passive validation. Corroboration processes that are more systematic and that involve the results of tests and associated procedures are classified as active validation processes.

The simulations of the models are classified as historical, ad hoc, and designed. Historical simulations refer to experiments with models in which the conditioning variables are entered as historical data series. Ad hoc simulations
refer to experiments in which the design points (values for conditioning variables, parameters, and so on) have been chosen in an intuitive or nonsystematic fashion. Designed simulations are those in which the experiments with the models have been developed using an experimental design. This implies the inclusion of an implicit or explicit response or objective function and the choice of a method of selecting design points which will produce the information required to identify the associated relationship.

Competitive games are defined as those in which the actions of one player or team do not affect the outcomes for other players or teams. In contrast, for noncompetitive games the outcomes are dependent upon player or team interactions.

Along with the above clarifications it should be noted that in the decision variable columns of tables 3-7 we report for behavioral and forecasting models the endogenous variables which refer to actions taken by the behavioral units, whereas for decision models we report those exogenous variables which refer to policy actions that might be taken by public or private decision makers. Second, the procedures for classifying models as linear or nonlinear are arbitrary; some models in which only weak departures from linearity exist are classified as linear models. Third, we classify as stochastic those models which are simulated stochastically (not constructed models which incorporate stochastic elements). Last, in the case of simulation models for which the computer language is unknown (for instance, because it was not reported and could not be inferred), Fortran is listed.

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<td>Ackoff [1971]</td>
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<td>Aigner [1972]</td>
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<td>Aitchison and Silvey [1958]</td>
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<td>Albert and Sittler [1965]</td>
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<td>Ansoff and Slevin [1968]</td>
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<td>Armstrong and Hepp [1970]</td>
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<td>Astrom and Wittenmark [1971]</td>
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Table 1. General References on Systems Simulation Analysis and Simulation (Cont.)

Chernoff [1972]  
Chorafas [1965]  
Churchman [1960, 1968, 1971]  
Clarkson and Simon [1960]  
Cochran and Cox [1957]  
Cohen and Cyert [1961, 1965]  
Conlisk and Watts [1969]  
Conway and Maxwell [1959]  
Cooper [1972]  
Coplin [1968]  
Cox [1961, 1962]  
Curry [1970]  
Cyert and March [1963]  
Davies [1954]  
Day [1971]  
Day and Sparling [1977]  
Dent and Anderson [1971]  
Department of Defense [1970]  
Deutsch [1969]  
Dhrymes et al. [1972]  
Donaldson and Webster [1968]  
Dorfman [1963, 1965]  
Drynan [1973]  
Early and Early [1972]  
Eidman [1971]  
Eisgruber and Nielson [1963]  
Eldor and Koppel [1971]  
Emery [1969]  
Emshoff and Sisson [1970]  
M. Evans [1969]  
Fel’dbaum [1965]  
Fine and McIsaac [1966]  
Finney [1945]  
Fisher [1962]  
Fishman and Kiviat [1967]  
Fletcher et al. [1970]  
Forrester [1961, 1968]  
Fox, Sengupta, and Thorbecke [1966]  
Freebairn and Rausser [1974]  
C. E. French [1974]  
Friedman [1971]  
Frisch [1935-36]  
Fromm [1969]  
Fromm and Taubman [1968]  
Gaver and Geisel [1974]  
Geisel [1970]  
Goldberg [1968]  
Gordon [1970]  
Granger and Hatanaka [1964]  
Gross and Ray [1965]  
Gunckel and Franklin [1963]  
Haitovsky and Wallace [1972]  
Halter, Hayenga, and Manetsch [1970]  
Hammersley and Handscomb [1964]  
Handscomb [1969]  
Hare [1967]  
Harbaugh and Bonham-Carter [1970]  
Harling [1958]  
Heady [1971]  
Hesselbach and Eisgruber [1967]  
Hill and Hunter [1966]  
Hinman and Hutton [1970]  
Hoggatt and Balderston [1963]  
Hollingdale [1967]  
Holt [1962]  
Holt et al. [1964]  
Hood and Koopmans [1953]  
Howrey [1971]  
Howrey and Kelejian [1969, 1971]  
Howrey and Klein [1972]  
Hufschmidt [1962]  
Hunter and Naylor [1970]  
IBM [1966a, 1966b]  
Ignall [1972]  
Ingram, Kain, and Ginn [1973]  
Jeffreys [1961]  
John [1971]  
B. Johnson and Eisgruber [1969]  
G. L. Johnson [1970]  
G. L. Johnson and Zerby [1973]  
H. G. Johnson [1951]  
S. R. Johnson, Tefertiller, and Moore [1967]  
Jorgenson, Hunter, and Nadiri [1970]  
Judge [1968, 1977]  
Judge and Yancey [1969]  
Kagel et al. [1975]  
Kalman [1960]  
Kiviat [1967]  
Kiviat, Villanueva, and Markowitz [1968]  
Kleijnen [1972, 1974, 1975]
Table 1. General References on Systems Simulation Analysis and Simulation (Cont.)

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<td>Klein and Burmeister [1976]</td>
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<td>Kogan [1966]</td>
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<td>LaDue and Vincent [1974]</td>
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<td>Lavington [1970]</td>
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<td>Leamer [1970]</td>
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<td>A. M. Lee [1970]</td>
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<td>G. E. Lee [1974]</td>
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<td>Leontief [1971]</td>
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<td>MacCrimmon and Tota [1969]</td>
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<td>Maffei [1958]</td>
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<td>Malcolm [1960]</td>
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<td>Manetsch, Hayenga, et al. [1971]</td>
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<td>Marschak [1963]</td>
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<td>Marsden, Pingry, and Whinston [1974]</td>
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<td>Martin [1968]</td>
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<td>Meadows et al. [1972]</td>
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<td>Mehra [1974]</td>
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<td>Meier [1967]</td>
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<td>Meier, Newell, and Pazer [1969]</td>
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<td>Mendenhall [1968]</td>
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<td>Mesarovic, Macko, and Takahara [1970]</td>
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<td>Mihram [1972]</td>
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<td>Mize and Cox [1968]</td>
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<td>Moore [1914]</td>
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<td>Murphy [1968]</td>
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<td>Nagar [1969]</td>
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<td>Nance [1971]</td>
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<td>Naylor, Burdick, and Sasser [1967]</td>
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<td>Naylor and Finger [1967]</td>
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<td>Naylor, Wertz, and Wonnacott [1967, 1969]</td>
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<td>Nijkamp [1970]</td>
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<td>Optner [1960]</td>
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<td>Orcutt [1960]</td>
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<td>Orcutt et al. [1961]</td>
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<td>Patten [1971]</td>
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<td>Perkins, Cruz, and Sundararajan [1972]</td>
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<td>Popper [1959]</td>
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<td>Porter et al. [1966]</td>
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<td>Ramsey [1969]</td>
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<td>Ramsey and Zarembka [1971]</td>
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<td>Rausser and Johnson [1975]</td>
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<td>Rothenberg [1961]</td>
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<td>Samuelson [1947]</td>
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<td>Simon and Newell [1958]</td>
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<td>V. K. Smith [1973]</td>
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<td>V. L. Smith [1962, 1964]</td>
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<td>Snyder and Swackhamer [1966]</td>
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<td>Strotz and Wold [1960]</td>
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<td>Suttar and Crom [1964]</td>
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<td>Tarn [1971]</td>
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<td>H. C. Taylor [1929]</td>
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<td>Theil [1964, 1971]</td>
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<td>Thorbecke [1971]</td>
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<td>Tinbergen [1952]</td>
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<td>Tocher [1963]</td>
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<td>Tse [1974]</td>
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<td>Tse and Athans [1970, 1972]</td>
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<td>Tse and Bar-Shalom [1973]</td>
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<td>Tse, Bar-Shalom, and Meier [1973]</td>
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<td>Tyner and Tweeten [1968]</td>
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<td>Van Horn [1971]</td>
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<td>Vichnevetsky [1969]</td>
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<td>Wallace and Ashar [1972]</td>
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<td>Ying [1967]</td>
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<td>Zellner [1971]</td>
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<td>Zellner and Chetty [1965]</td>
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<td>Babb and Eisgruber [1966]</td>
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<sup>a</sup> Time Unit: U = Unspecified, M = Monthly, Y = Yearly.
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<tbody>
<tr>
<td>Bellman, Clark, et al. [1957]</td>
<td>Firms competing for a known consumer market</td>
<td>To provide a means of executive training using simulation techniques in a multiperson business game, stressing long-run policy decisions</td>
<td>U</td>
<td>Yes</td>
<td>Yes</td>
<td>Open</td>
<td>Price, production rate, marketing budget, research and development, investment</td>
<td>Yes</td>
<td>No</td>
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<tr>
<td>Bentz and Williams [1965]</td>
<td>Teams operate four egg-handling plants in Illinois</td>
<td>To examine relationship between a firm and its environment</td>
<td>Month</td>
<td>Yes</td>
<td>No</td>
<td>Closed</td>
<td>Input purchases, capital investments, prices paid</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Curtis [1968]</td>
<td>Managing a single farm</td>
<td>To evaluate the effectiveness of business simulation models for teaching farm business analysis and record keeping for high school and adult students (the simulation technique is compared with more traditional methods)</td>
<td>Year</td>
<td>Yes</td>
<td>No</td>
<td>Closed</td>
<td>Basic inputs, debt servicing, borrowing</td>
<td>Yes</td>
<td>No</td>
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<tr>
<td>Author(s)</td>
<td>Operating a single farm/operating a San Joaquin Valley farm</td>
<td>To examine the effects of limited capital, uncertainty, price cycles, specialization vs. diversification, etc., in management</td>
<td>Year</td>
<td>Yes</td>
<td>Yes</td>
<td>Closed</td>
<td>Crop levels, fertilizer (amounts and types), livestock, land, breeding stock purchased or sold</td>
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<tr>
<td>Eisgruber [1965]</td>
<td>Operating a single farm</td>
<td>To examine the effects of limited capital, uncertainty, price cycles, specialization vs. diversification, etc., in management</td>
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<tr>
<td>Faris, Wildermuth, and Pratt [1966]</td>
<td>Operating a San Joaquin Valley farm</td>
<td>To stress farm operating decisions</td>
<td>Year</td>
<td>Yes</td>
<td>Yes</td>
<td>Closed</td>
<td>Production levels, land purchased, machinery combinations</td>
<td></td>
<td></td>
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<tr>
<td>Frahm and Schrader [1970]</td>
<td>English (ascending bid) and Dutch (descending bid) auction markets compared with respect to (1) price variation, (2) speed of convergence, (3) average prices, and (4) observed equilibrium prices</td>
<td>To test hypotheses under a given situation</td>
<td></td>
<td></td>
<td></td>
<td>Open</td>
<td>Assigned selling price and marginal processing cost</td>
<td></td>
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<tr>
<td>Frazier, Narrie, and Rodgers [1970]</td>
<td>Livestock auction market</td>
<td>To determine the inherent inefficiencies of a given size and scale of auction markets and to evaluate systems simulations as a research and/or management tool</td>
<td>U</td>
<td>Yes</td>
<td>Yes</td>
<td>Closed</td>
<td>Utilization of facilities, storage capacity, length of entry and exit queues; volume of livestock</td>
<td></td>
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<thead>
<tr>
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<th>Computerized</th>
<th>Stochastic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuller [1968]</td>
<td>Connecticut Valley cash crop and dairy farm</td>
<td>To relate managerial principles to decision making</td>
<td>Year</td>
<td>Yes</td>
<td>Yes</td>
<td>Open</td>
<td>Production levels of crops and dairy</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Fuller, Ruggles, and Yergatian [1968]</td>
<td>New England brown egg poultry farm</td>
<td>To stress impact of trade-off between income and security</td>
<td>Year</td>
<td>Yes</td>
<td>Yes</td>
<td>Closed</td>
<td>Selection of marketing system, capital investments, production levels</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Greenlaw, Herron, and Rawdon [1962]</td>
<td>Firm selling single (unnamed) product in two regional markets; demand fluctuations present</td>
<td>To provide a dynamic experience in marketing decision making. To emphasize competitive interaction in marketing decision making and difficulties of internal organization</td>
<td>U</td>
<td>Yes</td>
<td>Yes</td>
<td>Open</td>
<td>Price, expenditure for sales force, national and local advertising; of less importance are production and transportation</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Greenlaw, Herron, and Rawdon [1962]</td>
<td>Physical production and distribution of goods; producer-wholesaler-retailer links emphasized</td>
<td>To examine order and inventory policies in a dynamic marketing situation</td>
<td>U</td>
<td>Yes</td>
<td>No</td>
<td>Open</td>
<td>Price, orders, inventory</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Hutton and Hinman [1968]</td>
<td>Farm planning exercise; user specifies situation and parameters that pertain to his concern</td>
<td>To evaluate alternative farm plans</td>
<td>Year</td>
<td>No</td>
<td>Yes</td>
<td>Open</td>
<td>Inputs, level of capital, financing, sales, technical coefficients, production levels</td>
<td>Yes</td>
<td>Yes</td>
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<td>Author(s)</td>
<td>Description</td>
<td>Timeframe</td>
<td>Scheme</td>
<td>Hypothesis</td>
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<td>Kay [1973]</td>
<td>Market, crops, livestock</td>
<td>Month</td>
<td>Yes</td>
<td>Yes</td>
<td>Open</td>
<td>To provide an aid in teaching farm and ranch decision making</td>
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<tr>
<td>Longworth [1970]</td>
<td>Australian dryland grazing and cropping farm</td>
<td>Year</td>
<td>Yes</td>
<td>Yes</td>
<td>Open</td>
<td>To weigh short-run tactical decisions vs. long-run strategy</td>
<td></td>
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<tr>
<td>McKenney [1962]</td>
<td>Firms selling three (similar) products</td>
<td>U</td>
<td>Yes</td>
<td>Yes</td>
<td>Open</td>
<td>To provide production planning experience and to demonstrate interdependence of functional decisions within a firm; stress is on time dimension</td>
<td></td>
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<tr>
<td>F. J. Smith and Miles [1967]</td>
<td>Managing a 640-acre farm</td>
<td>Month</td>
<td>Yes</td>
<td>Yes</td>
<td>Closed</td>
<td>To relate economic principles and farm management</td>
<td></td>
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<tr>
<td>V. L. Smith [1964]</td>
<td>Sellers make offers, buyers accept or reject; sellers and buyers both active in the market process; buyers make bids, sellers accept or reject</td>
<td>U</td>
<td>Yes</td>
<td>Yes</td>
<td>Open</td>
<td>To test hypothesis concerning the price equilibrium and adjustment behavior of markets under three market organization conditions</td>
<td></td>
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<tr>
<td>Vincent [1970b]</td>
<td>Farm construction and operation</td>
<td>Year</td>
<td>Yes</td>
<td>Yes</td>
<td>Open</td>
<td>To familiarize participants with problems faced in farm development</td>
<td></td>
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</tbody>
</table>

Crop acreage, fertilizer levels, acreage for purchase or rent, type of livestock operation
When to buy and sell, levels of output, capital, investments
Price, advertising expenditure, design and styling expense, production levels, investment in plant capacity and/or securities
Levels of production, land and machinery purchase
Trading session prices along with price limits
Production levels, land purchases, capital allocation
Table 2. Gaming Models in Agricultural Economics (Cont.)

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<tbody>
<tr>
<td>Walker and Halbrook</td>
<td>A 200-acre corn farm in the Great Plains area</td>
<td>To understand problems of growth under uncertainty</td>
<td>U</td>
<td>Yes</td>
<td>Yes</td>
<td>Closed</td>
<td>Livestock inventory and capital investment</td>
<td>No</td>
<td>Yes</td>
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<td>[1965]</td>
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<tr>
<td>Wehrly</td>
<td>Managing a farm on the southern plains of Texas</td>
<td>To demonstrate how plans made under perfect knowledge work out under &quot;average&quot; conditions</td>
<td>Year</td>
<td>Yes</td>
<td>Yes</td>
<td>Closed</td>
<td>Crop production levels</td>
<td>No</td>
<td>Yes</td>
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<td>[1967]</td>
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<tr>
<td>Whan and Richardson</td>
<td>Statistical model of auction market with application to Australian wool</td>
<td>To develop a simulation model of an auction market demonstrating the relationship between variation in valuation, price variation, and the number of independent bidders</td>
<td>U</td>
<td>Yes</td>
<td>Yes</td>
<td>Open</td>
<td>Product quality, price limits, number of bidders, size of lots</td>
<td>Yes</td>
<td>Yes</td>
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<td>[1969]</td>
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<sup>a</sup>U indicates an unspecified time dimension or one which was other than monthly or yearly.
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<tr>
<td>Albach [1967]</td>
<td>To formulate model of unstable firm growth</td>
<td>Sales, research, firm growth</td>
<td>Actual sales, planning time for new products</td>
<td>Yes</td>
<td>Passive</td>
<td>Ad hoc</td>
<td>FORTRAN</td>
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<tr>
<td>R. L. Anderson [1968]</td>
<td>To establish optimum crop patterns on irrigated farms based on preseason water supply estimates</td>
<td>Moisture conditions, water supply</td>
<td>Water allocation, acreage restrictions</td>
<td>No</td>
<td>Passive</td>
<td>Historical</td>
<td>FORTRAN</td>
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<tr>
<td>J. R. Anderson [1971]</td>
<td>To analyze effects of spatial diversification of wool growers in Australia on the economic profitability of the firm</td>
<td>Weather, state of pasture, emergency pasture plan, prices, financial situation</td>
<td>Feeding and selling - transfer strategies</td>
<td>Yes</td>
<td>Passive</td>
<td>Ad hoc</td>
<td>FORTRAN</td>
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<tr>
<td>Armstrong, Connor, and Strickland [1970]</td>
<td>To combine simulation and linear programming to study farm firm growth</td>
<td>Farm simulator for short term tactical decisions, an ex post linear programming routine</td>
<td>Choice of enterprise, production methods, production levels</td>
<td>Yes</td>
<td>Passive</td>
<td>Historical</td>
<td>FORTRAN</td>
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Table 3. Firm and Process Simulation Models in Agricultural Economics (Cont.)

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<th>Model Function</th>
<th>Simulation</th>
<th>Computer Language</th>
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<tbody>
<tr>
<td>Brooks [1962]</td>
<td>To model the C&amp;H sugar refinery at Crockett</td>
<td>Input, output, processing stations, demand, capacity</td>
<td>Production levels, input levels</td>
<td>Yes</td>
<td>Passive</td>
<td>Ad hoc</td>
<td>FORTRAN</td>
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<tr>
<td>Cloud, Frick, and Andrews [1968]</td>
<td>To determine the optimal date for hay harvesting</td>
<td>Output, machinery, weather</td>
<td>Scheduling of activities, selection of production mode, inputs</td>
<td>No</td>
<td>Passive</td>
<td>Designed</td>
<td>FORTRAN</td>
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<tr>
<td>Dent [1971]</td>
<td>To construct a model for a typical pig enterprise to investigate the impact of operational policies on the return to capital investment</td>
<td>Breeding, fattening, capital investing</td>
<td>Type of investment, management practices</td>
<td>Yes</td>
<td>Passive</td>
<td>Designed</td>
<td>DYNAMO</td>
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<tr>
<td>Donaldson and Webster [1968]</td>
<td>To utilize simulation to assist in selecting farm plans with highest gross margins</td>
<td>Production, resource revenue</td>
<td>Production preferences, input levels</td>
<td>No</td>
<td>Passive</td>
<td>Ad hoc</td>
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<tr>
<td>Doster [1970]</td>
<td>To use a simulator to help in formulating plans for a corn farm</td>
<td>Harvesting, hauling, handling, storage, marketing</td>
<td>Planting schedule, form and time of sale, harvest schedules, equipment utilization</td>
<td>No</td>
<td>Passive</td>
<td>Ad hoc</td>
<td>FORTRAN</td>
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<tr>
<td>Authors</td>
<td>Topic</td>
<td>Activities</td>
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<tr>
<td>Eidman, Dean, and Carter [1967]</td>
<td>To demonstrate Bayesian decision theory for management decisions under uncertainty using commercial turkey production as an example</td>
<td>Capital stock, production, mortality, net returns</td>
<td>Marketing strategy (contract or independent)</td>
<td>Yes</td>
<td>Passive Decision</td>
<td>Designed FORTRAN</td>
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<tr>
<td>Eisgruber and Lee [1971]</td>
<td>To specify a growth model of a farm firm within the context of the systems approach</td>
<td>Corn production, pig production</td>
<td>Corn and pig production plans, resource and purchase policies</td>
<td>Yes</td>
<td>Passive Decision</td>
<td>Designed FORTRAN</td>
<td></td>
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<tr>
<td>Glickstein et al. [1962]</td>
<td>To apply simulation to a cheese manufacturing plant to analyze production under varying conditions</td>
<td>Plant and equipment, supplies and services, labor</td>
<td>Purchasing policy, process scheduling</td>
<td>Yes</td>
<td>Passive Decision</td>
<td>Ad hoc FORTRAN</td>
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<tr>
<td>Goodall [1971]</td>
<td>To develop a model that describes the sheep-grazing activities of inland Australia</td>
<td>Production activities, initial inventories, managerial, weather</td>
<td>Production levels, managerial decision</td>
<td>Yes</td>
<td>Passive Decision</td>
<td>Historical DYNAMO</td>
<td></td>
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<tr>
<td>Halter and Dean [1965]</td>
<td>To use simulation in evaluating management policies under uncertainty using a large ranch as an example</td>
<td>Rangeland, feedlot, and weather environment</td>
<td>Purchasing, scheduling, and selling</td>
<td>Yes</td>
<td>Passive Decision</td>
<td>Ad hoc DYNAMO</td>
<td></td>
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<th>Simulation</th>
<th>Computer Language</th>
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</thead>
<tbody>
<tr>
<td>Harle [1968]</td>
<td>To use simulation in farm planning by concentrating on data production rather than data manipulation</td>
<td>Capital, production, risk</td>
<td>Method of production, production levels</td>
<td>Yes</td>
<td>Passive</td>
<td>Ad hoc</td>
<td>Not known</td>
</tr>
<tr>
<td>Hinman and Hutton [1970]</td>
<td>To incorporate a generally accepted theory of the firm into a simulator to handle many different farm situations</td>
<td>Production, resources, inventory, input, financial</td>
<td>Debt level, marketing strategy, investment, input levels, insurance</td>
<td>Yes</td>
<td>Passive</td>
<td>Behavioral</td>
<td>Ad hoc</td>
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<tr>
<td>Hutton [1966]</td>
<td>To use a simulation model of a dairy herd in the selection of a herd replacement policy</td>
<td>Inputs, outputs, capital, financial</td>
<td>Replacement and input levels</td>
<td>Yes</td>
<td>Passive</td>
<td>Decision</td>
<td>Designed</td>
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<tr>
<td>Patrick and Eisgruber [1968]</td>
<td>To measure the influence of managerial ability and capital market structure on the rate of farm firm growth</td>
<td>Managerial, resource, financial, expectations</td>
<td>Credit availability and terms, investment</td>
<td>Yes</td>
<td>Passive</td>
<td>Forecasting</td>
<td>Designed</td>
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<tr>
<td>Author(s)</td>
<td>Summary</td>
<td>Input, output, environment</td>
<td>Level of fertilizer to apply</td>
<td>Decision</td>
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<td>Software</td>
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<tr>
<td>Smith and Parks</td>
<td>To predict, on a probability basis, optimum levels of fertilizer application when drought is considered to be a random variable</td>
<td>Input, output, environment</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
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<td>[1967]</td>
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<tr>
<td>Sorensen and Gilheany</td>
<td>To evaluate different harvesting strategies on a sugar plantation</td>
<td>Harvest, cane hauling, milling, weather</td>
<td>Labor allocation and level, harvest scheduling, machinery assignment</td>
<td>Yes</td>
<td>Yes</td>
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<td></td>
<td>Designed</td>
<td></td>
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<tr>
<td>Tanago</td>
<td>To construct a simulation model of a farm, using different decision theoretic approaches for analyzing the output generated</td>
<td>Production, market, capital</td>
<td>Hay machinery investment, crop area, hours worked per week</td>
<td>Yes</td>
<td>Yes</td>
<td>Passive</td>
<td></td>
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<tr>
<td>[1973]</td>
<td></td>
<td></td>
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<tr>
<td>Van Kampen</td>
<td>To provide a simulation model that may be used to minimize total harvest cost over a number of years allowing for the influence of weather</td>
<td>Weather, crop activities, harvest costs</td>
<td>Number of combines, techniques of operating the combines, drying capacity, storage capacity</td>
<td>Yes</td>
<td>Yes</td>
<td>Passive</td>
<td></td>
</tr>
<tr>
<td>[1971]</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>ALGOL</td>
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<tr>
<td>Vincent [1970a]</td>
<td>To construct a model to explain the future state of poultry producers</td>
<td>Feed production, egg production, financial, capital</td>
<td>Investment levels, production levels, marketing strategy</td>
<td>Yes</td>
<td>Yes</td>
<td>Passive</td>
<td>Designed</td>
</tr>
<tr>
<td>Vincent [1970b]</td>
<td>To explain the use of a farm simulator that can be adapted to many different farm firms</td>
<td>Capital and credit, livestock and crops, machinery</td>
<td>Farm acquisition, type and quantity of capital stock, production levels</td>
<td>Yes</td>
<td>Yes</td>
<td>Passive</td>
<td>Designed</td>
</tr>
<tr>
<td>Wright and Dent [1969]</td>
<td>To measure the effect of withdrawing land from grazing to cropping for part of the year</td>
<td>Biological environment, market structure, input and output</td>
<td>Land allocation</td>
<td>Yes</td>
<td>No</td>
<td>Passive</td>
<td>Designed</td>
</tr>
<tr>
<td>Zusman and Amiad [1965]</td>
<td>To determine optimal farm plans under weather uncertainty</td>
<td>Weather, market, livestock, inventory, crop, seasonal</td>
<td>Production levels, livestock herd size, inventory levels, sales, purchases</td>
<td>Yes</td>
<td>Yes</td>
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</table>
Table 4. Market and Industry Simulation Models in Agricultural Economics

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<th>Model Function</th>
<th>Simulation</th>
<th>Computer Language</th>
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<tbody>
<tr>
<td>Armbruster et al. [1972]</td>
<td>To evaluate farm marketing boards as a means of increasing farm bargaining power: test case western late potato system</td>
<td>Production, marketing, bargaining</td>
<td>Negotiated price; production quotas, acreage, marketing allocation</td>
<td>Dynamic Yes, Stochastic Yes, Non-linear Yes</td>
<td>Passive</td>
<td>Decision</td>
<td>Designed</td>
<td>FORTRAN</td>
</tr>
<tr>
<td>Balderston and Hoggatt [1962]</td>
<td>To examine the dynamics of a market viewed as a complex system of behavior in which information is limited and costly</td>
<td>Timber growers, retailers, broker transactions</td>
<td>Price, output, financing</td>
<td>Dynamic Yes, Stochastic Yes, Non-linear Yes</td>
<td>N.A.</td>
<td>Behavioral</td>
<td>Designed</td>
<td>FORTRAN</td>
</tr>
<tr>
<td>Barnum [1971]</td>
<td>To measure the effect of the introduction of stochastic terms on the reliability of deterministic conclusions obtained from simulation of the foodgrains market in India</td>
<td>Price, production, income, imports</td>
<td>Government purchases, importation of P.L. 480 surplus foodgrains</td>
<td>Dynamic Yes, Stochastic Yes, Non-linear No</td>
<td>Passive</td>
<td>Decision</td>
<td>Designed</td>
<td>FORTRAN</td>
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<tr>
<td>References</td>
<td>Objectives</td>
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<td>Non-linear</td>
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<td>Model Function</td>
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<tr>
<td>Bell, Henderson, and Perkins [1972]</td>
<td>To analyze the fertilizer industry with respect to sources of raw materials, interrelationship between supply and demand</td>
<td>Production, storage handling, transporting, processing, sales, pollution</td>
<td>Input prices, fertilizer purchases, output levels</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Passive</td>
<td>Decision</td>
</tr>
<tr>
<td>Bender [1966]</td>
<td>To provide a basis for determining in what season of the year promotional activities should be concentrated and the effects of change in feed grain prices on the broiler industry</td>
<td>Costs, capacity, seasonal demand</td>
<td>Production levels, input levels, investment, purchases</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Passive</td>
<td>Behavioral</td>
</tr>
<tr>
<td>Benson [1969]</td>
<td>To develop a computer simulation model for inter-regional competition in the broiler industry that can answer questions at the firm, region, and industry levels</td>
<td>Firm, capacity, supply, demand, region</td>
<td>Production levels, feed purchased, production schedules, spatial allocations</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Passive</td>
<td>Behavioral</td>
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<td>Author(s)</td>
<td>Purpose</td>
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<tr>
<td>Benson, Bender, and Lofourcade [1972]</td>
<td>To develop a simulation model of the broiler industry to estimate the intensity of inter-regional competition and its sensitivity to changes in decision variables</td>
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<tr>
<td>Candler and Cartwright [1969]</td>
<td>To illustrate the use of experimental design and regression analysis in the estimation of functional relationships as a basis for deriving &quot;performance statistics&quot;</td>
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<tr>
<td>Cohen [1960]</td>
<td>To examine detailed aspects of business behavior and dynamic interaction among firms using the shoe-leather-hide sequence as an example</td>
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<tr>
<th>Variables</th>
<th>Demand, supply, capacity, producing regions, spatial markets</th>
<th>Financial, output prices, input prices</th>
<th>Choice of weights entering the performance function</th>
<th>Prices, production levels, orders, inventory levels, consumer expenditures</th>
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<tr>
<td>Allocation</td>
<td>Spatial allocations, price premiums, feed prices</td>
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<tr>
<td></td>
<td>To indicate the trading pattern changes and the potential for re-adjustment between alternative market organizations in 1975 under alternative assumptions</td>
<td>Transportation capacity, labor, beef, pork, regional</td>
<td>Regional production, regional consumption, regional allocation</td>
<td>Dynamic No</td>
<td>Passive</td>
<td>Forecasting</td>
<td>FORTRAN</td>
</tr>
<tr>
<td>Crom [1967]</td>
<td>To develop a means of studying historical and projected changes in the livestock-meat economy's market organization and structure</td>
<td>Pork, beef, inventory, production, foreign trade, demand, margins</td>
<td>Slaughter production levels, inventory levels, breeding, culling</td>
<td>Stochastic No</td>
<td>Passive</td>
<td>Behavioral</td>
<td>Historical FORTRAN</td>
</tr>
<tr>
<td>Crom and Maki [1965b]</td>
<td>To evaluate the operation of the milk stabilization program in California and to indicate the direction and magnitude of possible changes</td>
<td>Producers, processors, market share, demand, cost</td>
<td>Production, prices, advertising, government price regulation</td>
<td>Non-linear No</td>
<td>Passive</td>
<td>Behavioral</td>
<td>Designed FORTRAN</td>
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<td>Desai [1968]</td>
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<td>Key Variables/Indicators</td>
<td>Simulation Type</td>
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<td>Software</td>
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<tr>
<td>Duewer and Maki</td>
<td>To investigate the interrelationships and interactions among the various parts of</td>
<td>Producers, market slaughterers, processors, wholesalers, retailers, households</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Passive</td>
<td>Behavioral</td>
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<tr>
<td>[1966]</td>
<td>the livestock-meat industry from a systems analysis standpoint</td>
<td>Purchases, sales, production levels, entry, exit, transaction partner selection</td>
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<tr>
<td>B. C. French and Matsumoto</td>
<td>To develop economic information which may aid various groups of the Brussels</td>
<td>Production, freezer, fresh, inventory</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Passive</td>
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<tr>
<td>Matsumoto [1969]</td>
<td>sprouts industry in decision making</td>
<td>Marketing policy, sprout size, product allocations, inventory levels</td>
<td></td>
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<tr>
<td>Koenig, Hilmersen, and</td>
<td>To demonstrate how systems theory can be employed in the analysis and control of</td>
<td>Feed, labor, plants (broiler, pullet, egg), markets</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
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<td>Decision</td>
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<tr>
<td>Yuan [1969]</td>
<td>semiclosed biological processes of the type encountered in the agricultural</td>
<td>Sales, feed and labor inputs, government purchases</td>
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<tr>
<td>Krebs, Hayenga, and Lehker</td>
<td>To evaluate and compare various support and supply control policies for navy beans in the U.S. by means of simulation</td>
<td>Domestic supply and demand, foreign supply and demand</td>
<td>Government prices, support levels, marketing control, acreage control, supply allocation</td>
<td>Yes No Yes Passive Decision Ad hoc FORTRAN</td>
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<tr>
<td>Lavington [1970]</td>
<td>To construct a model applicable to markets for frequently purchased goods</td>
<td>Market, individual, consumer</td>
<td>Distribution, retail price, advertising policies</td>
<td>Yes Yes Yes Passive Decision N.A. FORTRAN</td>
<td></td>
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<tr>
<td>Manetsch [1974]</td>
<td>To describe work in progress on the development of a computer simulation model for the softwood plywood industry</td>
<td>Integrated producers, independent producers, integrated jobbers and office wholesalers, independent office wholesalers, less than carload retailers, less than carload markets, carload markets</td>
<td>Production levels, sales, inventory levels, prices</td>
<td>Yes No No Passive Behavioral Ad hoc FORTRAN</td>
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<tr>
<td>Author(s)</td>
<td>Objective</td>
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<tr>
<td>Naylor, Wallace, and Sasser [1967]</td>
<td>To simulate the textile industry and to present three alternative validation tests</td>
<td>Supply, demand, employment, profit, prices, investment, earnings</td>
<td>Advertising, inventory levels, investment purchases</td>
<td>Yes Yes No</td>
<td>Active Behavioral Historical</td>
<td>FORTRAN</td>
<td></td>
</tr>
<tr>
<td>Raulerson and Langham [1970]</td>
<td>To investigate the problems of fluctuating orange supplies and grower profits in the frozen concentrate orange juice sector of the Florida citrus industry</td>
<td>Growers, processors, retailers, consumers</td>
<td>Tree planting, tree removal, supply control, market allocations</td>
<td>Yes No No</td>
<td>Passive Decision Ad hoc</td>
<td>DYNAMO</td>
<td></td>
</tr>
<tr>
<td>Vernon, Rives, and Naylor [1969]</td>
<td>To explain the behavior of the tobacco industry and to evaluate the impact of the efforts of alternative governmental and managerial policies</td>
<td>Leaf production, price, cigarettes</td>
<td>Production levels, pricing, purchases, inventory levels</td>
<td>Yes No No</td>
<td>Passive Behavioral Historical</td>
<td>SIMULATE</td>
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<tr>
<td>Weymar [1968]</td>
<td>To describe and explain the nature of the dynamic response of the world cocoa industry to annual fluctuations in world cocoa production</td>
<td>World consumption, price, expectations, inventory</td>
<td>Inventory levels, consumer purchases, price and inventory levels</td>
<td>Yes Yes Yes</td>
<td>Active Behavioral Designed</td>
<td>FORTRAN</td>
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Table 4. Market and Industry Simulation Models in Agricultural Economics (Cont.)

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</thead>
<tbody>
<tr>
<td>Zymelman [1965]</td>
<td>To develop an analog computer solution for the stabilization of employment, prices, and profits in the cotton textile gray goods industry</td>
<td>Demand, production, price, inventory</td>
<td>Production levels, inventory levels, orders</td>
<td>Yes</td>
<td>No</td>
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<td>References</td>
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<tr>
<td>Blase, MacMillan, and Tung [1973]</td>
<td>To design a computer model to facilitate public decision making concerning local government revenues and expenditures</td>
<td>Expenditures, revenues, budgets</td>
<td>Tax rates, borrowings, expenditure levels</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Chen [1970]</td>
<td>To develop an agricultural submodel for the U.S. economy as a market sector simulator for forecasting sales of a major farm equipment manufacturer</td>
<td>Supply and demand for ten commodity classes (simultaneous), supply response of crops (recursive), corporate forecasting system</td>
<td>Production levels, marketings, inventory control, financial planning</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Edwards [1970]</td>
<td>To present a simple simulation model which generates alternative time paths of population, income, and employment in a two-region model for the U.S.</td>
<td>Two regions, each having employment, income, and population growth components</td>
<td>Migration levels, population growth, worker productivity levels</td>
<td>Yes</td>
<td>No</td>
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Table 5. Aggregate Simulation Models in Agricultural Economics (Cont.)

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<tbody>
<tr>
<td>Lin and Heady [1971]</td>
<td>To investigate whether slower technical change or more reliance on free markets would have lessened overcapacity and raised income for U.S. farms</td>
<td>Commodity markets, resource markets, production, income</td>
<td>Government farm programs on prices, income, resource employment technology</td>
<td>Dynamic: Yes, Stochastic: No, Non-linear: No, Validation: Active, Model Function: Decision, Simulation: Ad hoc</td>
</tr>
<tr>
<td>Lins [1973]</td>
<td>To construct a simulation model of farm sector which can be used to evaluate policies concerning the financial structure of the farm sector</td>
<td>Farm and non-farm income, real estate, capital consumption, financed assets, inventories</td>
<td>Financial debt, capital investments, land purchases</td>
<td>Dynamic: Yes, Stochastic: No, Non-linear: No, Validation: Passive, Model Function: Decision, Simulation: Ad hoc</td>
</tr>
<tr>
<td>Authors</td>
<td>Purpose</td>
<td>Methodology</td>
<td>Technology</td>
<td>Econometric Methods</td>
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<tr>
<td>McFarquhar and Evans [1971]</td>
<td>To project changes in production and consumption of food and agricultural products in the U.K. between 1968 and 1975</td>
<td>Consumption, agricultural supply, input-output model, wheat, barley, cattle, sheep</td>
<td>Yes Yes No Passive Forecasting</td>
<td>YES Passive Decision Designed FORTRAN</td>
</tr>
<tr>
<td>Schaller [1968]</td>
<td>To outline the research on a national economic model of production response developed by the Farm Production Economics Division, Economic Research Service</td>
<td>Production response, input-output equilibrium</td>
<td>Yes No No Passive Decision Historical</td>
<td>FORTRAN</td>
</tr>
<tr>
<td>Shechter and Heady [1970]</td>
<td>To apply simulation models in deriving response surfaces for policy analysis in the feed-livestock sector</td>
<td>Micro level (individual firm units), macro level (aggregate output variables of all firms)</td>
<td>Minimum acreage No Yes Yes Passive Decision Designed</td>
<td>FORTRAN</td>
</tr>
<tr>
<td>References</td>
<td>Objectives</td>
<td>Components</td>
<td>Decision Variables</td>
<td>Model Characteristics</td>
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<tr>
<td>Tyner [1967]</td>
<td>To investigate the productivity of aggregate farm inputs and to develop a model to predict the impact of changes in government diversions, payments to farmers, acreage controls, price supports</td>
<td>Input, output, market, farm financial, nonfarm sector</td>
<td>Government programs as listed under &quot;objectives&quot;</td>
<td>Yes</td>
</tr>
<tr>
<td>Tyner and Tweeten [1968]</td>
<td>To present a methodology that can be used to study issues of farm-nonfarm interaction</td>
<td>Input, output, market, farm financial, nonfarm sector</td>
<td>Government payments to farmers, diversions of crop-land</td>
<td>Yes</td>
</tr>
<tr>
<td>References</td>
<td>Objectives</td>
<td>Components</td>
<td>Decision Variables</td>
<td>Model Characteristics</td>
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<tr>
<td>Aldabe and van Rijckeghem [1966]</td>
<td>To use simulation for quarterly forecasting of the Argentina cattle stock and its main components</td>
<td>Slaughter, herd death and birth rates</td>
<td>Mortality rates, fertility coefficients, stock levels</td>
<td>Yes</td>
</tr>
<tr>
<td>Billingsley and Norvell [1971]</td>
<td>To build an economic demographic simulation model to project the economic effects of changing the population growth rate of the Dominican Republic</td>
<td>Fertility, population, gross national product, mortality and birth rates</td>
<td>Government supported fertility control, labor force participation</td>
<td>Yes</td>
</tr>
<tr>
<td>Day and Singh [1971], Singh and Day [1972]</td>
<td>To explain the transition from subsistence or traditional agriculture to commercialized modern agricultural in the Indian Punjab through accounting for strategic details</td>
<td>Farm activities and decision variables within regions, annual objective function, technology matrix, technical constraints representing regional resource limitations, behavioral relations</td>
<td>Technology adaptation, crop mix, resource use</td>
<td>Yes</td>
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<td>Objectives</td>
<td>Components</td>
<td>Decision Variables</td>
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<td>Foster and Yost [1969]</td>
<td>To study and clarify the relationship between population growth, expenditures on education, and economic development in an underdeveloped rural economy</td>
<td>including adaptive mechanisms, feedback functions, exogenously given prices and supplies of variable production factors</td>
<td>Resource allocation, schooling, birth, education expenditures</td>
<td>Yes  Yes  No</td>
</tr>
<tr>
<td>Gillespie and Holland [1963]</td>
<td>To report on some exploratory experiments in economic dynamics performed on a simulated underdeveloped economy</td>
<td>Demographic, educational, income</td>
<td>Investment allocation, foreign trade policies, anti-inflation policies, exchange rates and tariff levels</td>
<td>Yes  No  Yes</td>
</tr>
<tr>
<td>Authors</td>
<td>Objective</td>
<td>Model Components</td>
<td>Yes/No</td>
<td>Active/Passive Decision</td>
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<tr>
<td>Hayenga, Manetsch, and Halter [1968], Halter and Manetsch [1970]</td>
<td>To illustrate the application of simulation as a problem-solving approach to the development of the Nigerian agricultural economy</td>
<td>Regional (southern tree and root crops and northern annual crops and livestock) inputs, production, marketing, consumers, trade, population</td>
<td>Marketing board prices, production research and extension expenditures, taxes and subsidies, infrastructure investments</td>
<td>Yes  No  Yes</td>
</tr>
<tr>
<td>Holland [1962]</td>
<td>To examine the problems of economic development and foreign trade policy for an underdeveloped country</td>
<td>Production, export, consumer, capital</td>
<td>Public service, investment allocations and levels</td>
<td>Yes  No  Yes</td>
</tr>
<tr>
<td>Kresge [1967]</td>
<td>To present a general simulation model to be used for policy evaluations by developing countries with Pakistan as an example</td>
<td>Final demand, industrial production, income, regions</td>
<td>Level of investment and import substitution developments</td>
<td>Yes  No  No</td>
</tr>
<tr>
<td>Lehker and Manetsch [1971]</td>
<td>To examine the feasibility of using simulation to analyze the planning of beef production in Northeast Brazil</td>
<td>Nutritional cash crops, herd management, credit</td>
<td>Land use, production levels, sales policies, herd management modernization</td>
<td>Yes  No  Yes</td>
</tr>
<tr>
<td>References</td>
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<td>Decision Variables</td>
<td>Model Characteristics</td>
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</tr>
<tr>
<td>Manetsch [1974]</td>
<td>To describe the role of simulation models in the study of Korean rural development</td>
<td>Agricultural production, regional sectors, urban and rural consumption, population, prices</td>
<td>Policy alternatives: 1) increase food self-sufficiency and growth of rural income; 2) budget reallocation for rural development; 3) move agricultural sector to reliance on competitive markets</td>
<td>Yes, No, Yes, Passive</td>
</tr>
<tr>
<td>Manetsch, Hayenga, et al. [1971]</td>
<td>To develop a general system simulation approach for examining agricultural development which is operational</td>
<td>Regional agricultural sectors (northern annual crop-beef model and southern perennial annual crop model), nonfarm sectors</td>
<td>Land allocations, level of modernization, marketing board and export tax policies, investment allocation and levels</td>
<td>Yes, Yes, Yes, Active</td>
</tr>
<tr>
<td>Manetsch, Ramos, and Lenchner [1968]</td>
<td>To develop a computer simulation program for modernizing cotton production in northeast Brazil</td>
<td>Production, credit, transportation, processing, marketing, consumption</td>
<td>Research and extension expenditures</td>
<td>Yes, Yes, Yes, Passive</td>
</tr>
<tr>
<td>Study</td>
<td>Objectives</td>
<td>Simulation Elements</td>
<td>Allocation of Investment by Region and Production Mode, Adoption of Technology</td>
<td>Simulation Type</td>
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<tr>
<td>Manetsch and Lenchner [1971]</td>
<td>To develop a simulation model to compute the consequences of alternative development strategies for the Brazilian textile industry</td>
<td>Regions, production cloth type, inputs</td>
<td>Yes No Yes Passive Decision Historical FORTRAN</td>
<td></td>
</tr>
<tr>
<td>Mathis [1969]</td>
<td>To develop an economic model of the cocoa industry for the Dominican Republic which will be useful in evaluating the influence of investments and other policy decisions in an economic development program</td>
<td>Traditional farms, modern farms, extension, research, disease and pest control, credit, income, marketing and transportation, export and domestic consumption</td>
<td>Development loans, government expenditures, investment</td>
<td>Yes No Yes Active Decision Designed DYNAMO</td>
</tr>
<tr>
<td>MSU Agricultural Sector Simulation Team [1973]</td>
<td>To illustrate application of simulation techniques to problems of planning and policy making for the Nigerian agricultural sector</td>
<td>Regional inputs, production, marketing, consumption, trade, services, national accounts</td>
<td>Production levels, marketing decisions, technology introduction</td>
<td>Yes No Yes Passive Behavioral Designed FORDYN</td>
</tr>
<tr>
<td>References</td>
<td>Objectives</td>
<td>Components</td>
<td>Decision Variables</td>
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<tr>
<td>Miller and Halter [1973]</td>
<td>To illustrate the consequences through time of a set of policies estimated to shift the Venezuelan cattle industry from traditional to modern production</td>
<td>Traditional and modern beef production, crop sector, consumption</td>
<td>Price policies, land development, extension expenditures</td>
<td>Yes</td>
</tr>
<tr>
<td>Roberts and Kresge [1968]</td>
<td>To explore the interface between the economy of an underdeveloped nation and its transportation system using Colombia as an example</td>
<td>Final demand, industrial production income, interregional commodity flows, regional output, transportation costs</td>
<td>Choice of transport mode, transportation system expansion, output levels</td>
<td>Yes</td>
</tr>
<tr>
<td>L. J. Taylor [1969]</td>
<td>To examine structural change in sectoral output levels during the course of economic growth and to examine the forces underlying these patterns</td>
<td>Input, output, trade, consumption, industry production, primary production, services</td>
<td>Import substitution, government expenditures</td>
<td>Yes</td>
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### Table 7. Natural Resource Simulation Models in Agricultural Economics

<table>
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<tr>
<th>References</th>
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<th>Decision Variables</th>
<th>Model Characteristics</th>
<th>Computer Language</th>
</tr>
</thead>
<tbody>
<tr>
<td>R. L. Anderson and Maass [1974]</td>
<td>To develop and test procedures by which operators and builders of irrigation systems can compare and evaluate alternative methods of distributing water among farmers</td>
<td>Production benefits, water allocation, water supply</td>
<td>Crop levels, water sequencing, operating procedure to deliver water, selection of crops to be irrigated</td>
<td>Dynamic, Stochastic, Non-linear, Passive, Decision, Designed</td>
<td>FORTRAN</td>
</tr>
<tr>
<td>Askew, Yeh, and Hall [1971]</td>
<td>To simulate critical periods of drought to assist in the planning and construction of reservoirs and to compare generating techniques</td>
<td>Rivers, stream flow</td>
<td>Maximum permissible extraction rate, duration of low stream flow and the accumulated deficiency relative to the mean flow</td>
<td>Dynamic, Stochastic, Non-linear, Passive, Behavioral, Designed</td>
<td>FORTRAN</td>
</tr>
<tr>
<td>Chen [1971]</td>
<td>To develop a costing procedure which will be a practical and useful tool in planning cottage resorts</td>
<td>Investment, cost</td>
<td>Type of accommodations, secondary business facilities, outdoor recreational facilities, length of season</td>
<td>No, Yes, No, Active, Behavioral, Designed</td>
<td>FORTRAN</td>
</tr>
</tbody>
</table>
Table 7. Natural Resource Simulation Models in Agricultural Economics (Cont.)

<table>
<thead>
<tr>
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<th>Components</th>
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<th>Model Characteristics</th>
<th>Model Function</th>
<th>Simulation</th>
<th>Computer Language</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chow and Kareliotis</td>
<td>To formulate a mathematical model of a stochastic hydrologic system</td>
<td>Precipitation, runoff, storage</td>
<td>Conceptual watershed storage, stream flow</td>
<td>Dynamic Yes Non-linear Yes Yes Passive Behavioral Historical</td>
<td></td>
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<td>FORTRAN</td>
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<tr>
<td>[1970]</td>
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<tr>
<td>Dudley and Burt</td>
<td>To estimate the long-run optimal area to develop for irrigation, given the size of a reservoir</td>
<td>Water supply, water demand, crops, moisture, costs</td>
<td>Acreage to be developed for irrigation</td>
<td>Dynamic Yes Non-linear Yes Yes Passive Decision Ad hoc</td>
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<td>FORTRAN</td>
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<td>[1973]</td>
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<tr>
<td>Ellis</td>
<td>To present a systems model of recreational activity in Michigan that can be utilized to predict the outcome of proposed changes or innovations</td>
<td>Population centers, transportation, destination</td>
<td>Activity by type of recreation and location</td>
<td>Non-linear Yes Passive Decision Ad hoc</td>
<td></td>
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<td>FORTRAN</td>
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<tr>
<td>[1966]</td>
<td></td>
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<tr>
<td>Halter and Miller</td>
<td>To test the applicability of simulation in evaluating water resource de-</td>
<td>Hydrologic flows, upstream and downstream flows, costs, benefits, drainage</td>
<td>Size of proposed reservoir and channel capacity, channel improvements</td>
<td>Dynamic Yes Non-linear Yes Yes Passive Decision Designed</td>
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<td>DYNAMO</td>
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<td>[1966]</td>
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<td>Study</td>
<td>Objective</td>
<td>Outputs</td>
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<td>Decision Making</td>
<td>Model Type</td>
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<tr>
<td>Hamilton et al. [1969]</td>
<td>To apply systems simulation to regional analysis, specifically the Susquehanna River basin</td>
<td>Demographic, employment, water (quantity and quality), spatial</td>
<td>Yes</td>
<td>No</td>
<td>Active Forecasting</td>
<td></td>
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</tr>
<tr>
<td>Howitt et al. [1974]</td>
<td>To project the impact of changing water quality in the Salton Sea of California on the recreational use and the investment climate for recreational facilities</td>
<td>Water quality, recreational activities and facilities</td>
<td>Yes</td>
<td>No</td>
<td>Passive Decision</td>
<td></td>
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</tr>
<tr>
<td>Hufschmidt [1963]</td>
<td>To find an optimal design for a given river basin system</td>
<td>Reservoirs, hydro-power plants, irrigation system, flood damage system</td>
<td>Yes</td>
<td>Yes</td>
<td>Passive Decision</td>
<td></td>
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</tr>
<tr>
<td>References</td>
<td>Objectives</td>
<td>Components</td>
<td>Decision Variables</td>
<td>Model Characteristics</td>
<td>Computer Language</td>
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<tr>
<td>Hufschmidt and</td>
<td>To outline a procedure for water resource simulation with an application to the Lehigh River basin</td>
<td>Supply of water, demand for water-derived products and services, flood, energy, temporal, benefits</td>
<td>Hydrologic conditions, dam and reservoir capacities, type of irrigation works, size of power plants, levels of flood damage alleviation</td>
<td>Yes</td>
<td>Passive Decision Designed FORTRAN</td>
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<tr>
<td>Fiering [1966]</td>
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</tr>
<tr>
<td>Huggins and</td>
<td>To develop a model to simulate the surface runoff from watersheds by delineating the model to a grid of small independent elements</td>
<td>Rainfall, runoff</td>
<td>Rainfall interception, infiltration</td>
<td>No</td>
<td>Active Behavioral Historical FORTRAN</td>
<td></td>
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<tr>
<td>Monke [1968]</td>
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<td></td>
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<td></td>
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</tr>
<tr>
<td>Jacoby [1967]</td>
<td>To develop a model to evaluate major investment and operating decisions for electric power planning using West Pakistan as an example</td>
<td>Costs, agricultural sector, irrigation water, electrical power, foreign exchange rates, power demand, spatial markets</td>
<td>Size and location of multipurpose hydroelectric and irrigation development, operating rules, type of plant</td>
<td>Yes</td>
<td>Passive Decision Designed FORTRAN</td>
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</table>

Table 7. Natural Resource Simulation Models in Agricultural Economics (Cont.)
<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Objective</th>
<th>Variables Considered</th>
<th>Model Characteristics</th>
<th>Language</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leistritz [1970]</td>
<td>To determine forces that have major influence on the farm real estate market</td>
<td>Supply, demand, farm size</td>
<td>Passive Behavioral Designed FORTRAN</td>
<td></td>
</tr>
<tr>
<td>McMahon and Miller [1971]</td>
<td>To demonstrate the proper use of a first-order non-seasonal Markov model with skewed data in the synthetic generation of stream flows</td>
<td>Hydrologic flows</td>
<td>Active Behavioral Historical FORTRAN</td>
<td></td>
</tr>
<tr>
<td>Masch and Associates [1971]</td>
<td>To develop a set of interrelated water-quality models capable of routing water quality parameters through a stream subsystem</td>
<td>Thermal behavior, waste assimilation, routing of conservative minerals, spatial, water quality, runoff</td>
<td>Active Behavioral Designed FORTRAN</td>
<td></td>
</tr>
<tr>
<td>Miernyk [1969]</td>
<td>To develop a model as a basis for long-range projections of economic activity in the Colorado River basin with water quality and quantity constraints</td>
<td>Water supply, water demand, spatial, production, agricultural, commercial, industrial, municipal sectors</td>
<td>Passive Forecasting Designed FORTRAN</td>
<td></td>
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Table 7. Natural Resource Simulation Models in Agricultural Economics (Cont.)

<table>
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<th>References</th>
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<th>Components</th>
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<th>Model Characteristics</th>
<th>Model Function</th>
<th>Simulation</th>
<th>Computer Language</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pisano [1968]</td>
<td>To provide a set of options to be used in river basin planning for water quality management</td>
<td>Water quality, stream flows, reservoir levels, pollutant concentrations</td>
<td>Various combinations of reservoir sizes, reservoir releases and waste input schedules, water quality standards</td>
<td>Dynamic Yes, Stochastic Yes, Non-linear Yes</td>
<td>Active</td>
<td>Behavioral</td>
<td>Designed</td>
</tr>
<tr>
<td>Rausser, Willis, and Frick [1972]; Rausser and Willis [1976]</td>
<td>To determine the probability distribution of the external learning benefits emanating from the construction of a water desalting plant, and how subsidy measures based upon these benefits influence capital investments and water allocations</td>
<td>Learning, desalting plants, costs, external benefits, fresh water transport, reservoirs, use sectors and their demand for water</td>
<td>Public subsidies, investment sequencing of alternative water source developments, water allocation</td>
<td>Dynamic Yes, Stochastic Yes, Non-linear Yes</td>
<td>Passive</td>
<td>Decision</td>
<td>Designed</td>
</tr>
<tr>
<td>Rodriguez-Iturbe,</td>
<td>To compare various Markovian</td>
<td>Stream flows</td>
<td>Seasonal structure, periodicity,</td>
<td>Dynamic Yes, Stochastic Yes, Non-linear Yes</td>
<td>Active</td>
<td>Behavioral</td>
<td>Designed</td>
</tr>
<tr>
<td>Author(s)</td>
<td>Description</td>
<td>Model Characteristics</td>
<td>Type of Abatement Program</td>
<td>Decision Models</td>
<td>Model Languages</td>
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<tr>
<td>Dawdy, and Garcia [1971]</td>
<td>models with respect to their adequacy in the preservation of the required reservoir storage characteristics of the historical record</td>
<td>cyclic variation, random filters</td>
<td>Passive Behavioral Historical FORTRAN</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Shih and Dracup [1961]</td>
<td>To use a hybrid computer simulation model to solve the three-dimensional non-uniform diffusion equations for determining evaporation from finite areas of water</td>
<td>Wind, temperature, humidity, atmospheric pressure</td>
<td>No No Yes</td>
<td>Passive Decision Historical FORTRAN</td>
<td></td>
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</tr>
<tr>
<td>Stillson [1969]</td>
<td>To outline a regional trade model to determine the economic impact of proposed pollution abatement programs for the western basin of Lake Erie</td>
<td>Tradable commodities, untradable commodities, transportation system, costs, prices, final demand, spatial</td>
<td>No No No</td>
<td>Passive Decision Historical FORTRAN</td>
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</table>
Notes

1. The term "nonprimitive" is used to indicate the theoretical content of these models. As the level of abstraction increases, the behavioral notions on which the model is based become more primitive. Most systems models are based on intuitive or ad hoc specification and thus are often highly specialized.

2. The more frequently quoted definitions may be found in Chorafas [1965], Churchman [1960, 1968], Emery [1969], and Orcutt [1960]. In a more recent examination Churchman [1971] suggests nine necessary conditions for the existence of a system. A system (1) must be goal seeking, (2) must involve a measure of performance, (3) must have a client whose interests are served by the system, (4) must have components which are goal seeking and which jointly influence the measure of system performance, (5) must have an environment which also influences the measure of performance, (6) must involve a decision maker who can influence the measure of system performance, and (7) must involve a designer who conceptualizes the nature of the system; furthermore, (8) the designer's intention must be to change the system so as to maximize its value to the client, and (9) the designer's intention must be ultimately realizable.

3. The literature on this subject is extensive. For example, Monte Carlo methods have been used to study sampling properties of parameter estimators in econometric models (V. K. Smith [1973]). This connection between Monte Carlo and simulation methods suggests a number of avenues the survey might take. The more traditional Monte Carlo applications, particularly for examining properties of estimates, are quite interesting but are outside the purview of this survey.

4. J. R. Anderson [1974a] and LaDue and Vincent [1974] have suggested that the identification of certain types of simulations as gaming is not a useful distinction. We would concur. The delineation is useful, however, for purposes of the present survey, since gaming applications have developed in some very distinctive directions.

5. This discussion and the subsequent one for the most part do not consider the actual complexity of selecting among alternative model specifications (Geisel [1969]). Classical techniques are largely silent in the case of non-nested hypotheses or the disparate families of hypotheses represented by alternative model representations. Cox [1961, 1962] and Atkinson [1970] have examined such techniques in the context of non-nested hypotheses. Unfortunately, the tests developed by these authors cannot be performed in any routine manner and are rather costly. This is because the developed test statistic depends on the nature of the hypotheses to be tested.

6. For the use of a range of arbitrary algebraic specifications of multidimensional utility functions to summarize simulations results, see Fromm and Taubman [1968]. More general discussions of performance function specification and estimation are presented by Rauser and Johnson [1975] and Rothenberg [1961]. Of all the approaches considered, the implicit performance function estimation proposed by Nijkamp [1970] is perhaps the most practical.

7. It would be easy to review some of the process model studies conducted—for example, in California during the 1950s—and to conclude that, although not recognized as such, the research methods employed were closely akin to what is now termed systems analysis.

8. The Cohen study is the original reference to the validation procedure of regressing simulated endogenous values on actual endogenous values (or vice versa) and testing the null hypothesis that the intercept coefficient of this regression equals zero and the as-
associated slope coefficient equals unity. As shown in Aigner [1972] and Rausser and Johnson [1975], this procedure is incorrect in the context of stochastic simulation.

9. Process simulation was first characterized by Cohen [1960], who differentiated this concept from one-period change models. The latter models utilized actual historical data to generate simulated values and were unfortunately characterized by Cohen [1960] as being coincidental with econometric models. This has caused some confusion in the literature (LaDue and Vincent [1974]); econometric models can obviously be simulated on either a one-period basis or a process basis. The dichotomy is, in fact, equivalent to the distinction between ex post and ex ante generated values of endogenous variables in a forecasting context.

10. Specifically, it was found “possible to cut cost by 67 percent and reduce surplus accumulation by 46 percent below the lowest corresponding benchmark values of these responses. Similarly average income was raised by about 10 percent. However, only a slight improvement, 3 percent, was achieved in participant income” (Shechter and Heady [1970]).

11. For detailed comparisons of alternative sectoral models with specific reference to their uses in planning and program design, see Thorbecke [1971].

12. Kain and Meyer [1968] also cite a number of computer simulation applications to regional and urban problems, metropolitan growth, and community renewal.

13. The “curse of dimensionality” refers to the fact that when control variables and time periods are increased the solution space for dynamic programming problems becomes large and quite complex (Bellman [1961]).

References


Aldabe, H., and W. van Rijckeghem [1966]. The Use of Simulation for Forecasting Changes in the Argentine Cattle Stock. Paper presented to Development Advisory Service Conference, Bellagio, Italy.


Experiments with a Biomanagement Model of a Deer Herd. Oregon Agricultural Experiment Station Technical Paper 3124.


Black, J. D. [1924]. "Elasticity of Supply of Farm Products." J. Farm Econ. 6:145-155.


Day, R. H., and E. Sparling [1977]. "Optimization Models in Agricultural and Resource Economics." (See the table of contents in this volume.)


Doster, D. H. [1970]. "Extension Uses of Simulation in Evaluating Corn Harvesting Systems." Purdue University, Department of Agricultural Economics.


Eisgruber, L. M. [1965]. Farm Operation Simulator and Farm Management Decision Exercise. Purdue University Agricultural Experiment Station Progress Report 162.


Faris, J. E., and J. Wildermuth [1966]. The California Farm Management Game. University of California Agricultural Experiment Station and Giannini Foundation of Agricultural Economics.


French, B. C., and M. Matsumoto [1969]. An Analysis of Price and Supply Relation-


Fuller, E. I. [1968]. *The Use of the Northeast Farm Management Game in Massachusetts*. University of Massachusetts, Department of Food and Agricultural Economics. Mimeo.

Fuller, E. I., L. Ruggles, and C. Yergatian [1968]. *Massachusetts Poultry Farm Management Game, Players Information, Year 1 and Year 2*. University of Massachusetts, Department of Food and Agricultural Economics.


Johnson, B., and L. M. Eisgruber [1969]. Annotated Bibliography on Simulation in Business Management. Purdue University, Department of Agricultural Economics.


—— [1977]. "On Estimating the Parameters of Economic Relations." (See the table of contents in this volume.)


Kay, R. D. [1973]. *Texas A & M Farm and Ranch Management Game*. Texas A & M University, Department of Agricultural Economics and Rural Sociology, Departmental Program and Model Documentation 73-1.


Simfarm 1: A Farm Business Simulator and Farm Management Game. Michigan State University, Agricultural Economics Report 164.


