University of California, Davis
Department of Agricultural Economics

A SURVEY OF SYSTEMS ANALYSIS AND SIMULATION IN AGRICULTURAL ECONOMICS

by

S. R. Johnson and Gordon C. Rausser

1972

SYSTEMS ANALYSIS

I. INTRODUCTION

Preliminary Comments

Systems analysis and simulation are concepts which have had a substantial impact upon teaching and research efforts in Agricultural Economics during the past decade. They have facilitated the extension of research efforts within the profession to new and eclectic types of problems as well as suggested avenues of attack for problems of more traditional origins. Presenting a competent survey is, therefore, a task of considerable magnitude. We turn to the task with some misgiving and, of course, with some preconceptions. In the remainder of this section we attempt to develop some perspective for the principal elements of our examination. These general comments are designed to provide some insights as to our preconceptions and a very general view of the methodological considerations implicit in the use of the research approach embodied in these techniques and methods.

The Systems Analysis - Simulation Approach

Although the terms systems analysis and simulation are often used synonymously, the two are in a technical sense quite different. At the basis of the modern works involving systems analysis and simulation is the very broadly defined idea of a system. The primitive concepts on which the notion of a system rests are those of elements and relations.[1] To

---

Paper presented to the American Agricultural Economics Association Annual Meeting, Gainesville, Florida, August 20-23, 1972.

borrow from Ackoff, "A system can be defined as an entity which is composed of at least two elements and a relation that holds between each of its elements and at least one other element in the set," (Ackoff, 1971). The feature of this notion which represents a departure from more traditional problem conceptualizations is the complexity of the subjects the idea of a system can embrace. Since according to the strict interpretation of this definition of a system, each of its elements is connected with every other element and the types of relation are unspecified, the systems approach can be extended to a wide variety of subjects.

Systems analysis is simply the study of systems. It is common to study these systems through the construction of models or analogs orientated towards specific types of problems. Due to the complexity of the systems and, therefore, their representations it is often difficult to handle the problems posed in the context of the models directly. Instead we experiment with the model of the system in a number of ways to obtain the required information. The process of experimenting with economic systems or more properly representations of systems as perceived by individuals is called simulation (Naylor, 1971).

The rather natural assimilation of the systems analysis - simulation approach into the Agricultural Economics literature may, of course, be attributed to many factors. Although it is fashionable in surveys of this type to attribute the adoption of systems analysis and simulation techniques to the development of large scale computers, we shall concentrate instead upon other aspects of the research and teaching within Agricultural Economics. This orientation will hopefully provide more useful insights for understanding the increasingly wide-spread use of the approach. This is not to say that high speed and relatively inexpensive computational facilities are unimportant in encouraging the use of systems analysis and simulation. Instead we assert that since such facilities are not unique to Agricultural Economics and since their importance has been outlined in a number of other places,[2] they can be of only limited interest in terms of revealing the reasons for the rather receptive attitude of the profession towards the approach.

The characteristics of the profession which appear worth outlining in providing a basis for the survey are: (i) the pragmatic or problem focused orientation, (ii) the increasingly eclectic nature of such problems and (iii) the concern with the extension of knowledge to government and industry and, relatedly, the need for powerful pedogogical devices.[3] Although these aspects of Agricultural Economists are by no means exhaustive in terms of explaining the assimilation of systems analysis and simulation methods, they suffice to indicate some issues which deserve attention. As these characteristics provide a theme for much of the commentary in the survey, they are briefly developed at this point.

The pragmatic or problem focused orientation of the profession is obviously due principally to its applied nature. Research efforts are in fact usually designed so as to bring the available information—both that which might be suggested by theory and institutions and that which might be ascertained from available data—to bear on particular types of problems which arise in the public and private sectors of Agriculture. The mission is, therefore, not so much to investigate the subtleties of theory or institutional considerations (although "tests" of theory and institutional hypothesis are surely a part of the process of knowledge accumulation) but to provide a basis for informed decisions regarding the problems under examination. If this admittedly over simplified conception of research efforts is reasonable, then the above observation is useful in terms of explaining the extent to which systems analysis and simulation techniques have been employed. For as we shall argue, it is in this situation that the systems analysis characterization of research models and the simulation technique for studying the implications of such models seems to be most appealing.

The second characteristic isolated for special attention was the eclectic nature of the problems studied by the profession. As the interests of the profession have broadened to include more emphasis on natural resources, community development, economic development, firm and market decisions problems involving truly dynamic and stochastic elements, and large scale policy questions at regional and national levels there has been a rather natural emphasis on the systems analysis and simulation approach. Models employed in studying such problems typically involve theoretical considerations which are to some extent unresolved. In addition, the large scale versions of these models frequently incorporate theoretical considerations which cut across traditional discipline boundaries. Under these circumstances it is worthwhile (in terms of obtaining results with more immediate applicability) to specify the theoretical components of the models in non-primitive forms and even to experiment with the predictive power of the models and their reasonableness in terms of alternative types of behavioral assumptions. It will be clear from our subsequent discussion that systems analysis as a modelling concept can be useful under these types of circumstances.

A related aspect of these eclectic models concerns technical questions associated with their solution. As the previous discussion would indicate, many types of models or problems currently investigated by Agricultural Economists do not lend themselves to solution by analytical methods. In the absence of efficient methods of solution it is natural to numerically solve or simulate such models. These simulations or experiments can be based on approximations of analytical solutions, investigating the multidimensional response surfaces of the endogenous variables or simply monitoring the output of the model under assumed settings of decision or control variables. Whatever the case, it is clear that as models become more eclectic in nature both with regard to discipline boundaries and orders of complexity, the simulation method for studying their behavior becomes not only more useful but also necessary.

The last characteristic to which we draw attention involves the importance of the extension knowledge. Since Agricultural Economics is applied in nature it may be presumed that there should be concern with transmitting research results to students, governmental officials, and agents in the industry being serviced. The systems analysis - simulation approach turns out to have some decided advantages in connection with these areas of interest.[4] As the subsequent discussion shows, the systems modelling and simulation approach is a useful technique for communicating complex types of ideas and information. Without completely anticipating the points to be subsequently developed, we note that these advantages result from the comparative ease with which such models can be described and from the possibility of allowing interaction between individuals and the models.

Our purpose to this point has been to suggest the breadth of applicability for the systems analysis - simulation approach to problems in Agricultural Economics. We have also implicitly argued that the flexibility inherent in the approach is one of its major attributes. That is, the systems analysis approach may be viewed as a comparatively unconfining method of handling research and teaching problems. In the ensuing discussion we shall attempt to substantiate this aspect of the approach as a major attribute.[5] It turns out, however, that a price must be paid for this flexibility. Moreover, the price of this flexibility has been partially obscured in the Agricultural Economics literature.[6] As a consequence, we will attempt to be careful in pointing out these shortcomings--not with purpose of suggesting that the approach is inappropriate but rather with the view that a balanced survey must provide information concerning past applications of the approach and also generate a reasonable perspective for viewing the approach as well as the results it has facilitated.

Some Historical Observations

Given the preceding discussion of the factors which have influenced the assimilation of the systems analysis and simulation approach some observations on possible historical origins may be appropriate. As we have previously argued, the novelty if any, which emanates from the systems approach is concerned with the flexibility provided in model conceptualization, estimation and application. In viewing the development of Agricultural Economics and particularly that portion of the development which can be identified with model building, three rather easily identifiable periods are discernible. Early efforts were highly empirical in origin. Studies of farm management and industry organization were largely descriptive, (Taylor, 1929). Hypotheses and models were suggested largely by observation of the subjects being studied and formed with little in the way of preconceptions suggested by deductive theory.[7] Once formulated the models or hypotheses were subjected to additional empirical information as a basis for evaluation. In short, during this first period the profession had empiricism as its principal orientation.

The second period to which we refer began in the late 1930's and was strongly influenced by some parallel developments in economic and statistical theory. Specifically, 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 then an increased preoccupation with the deductive basis for the hypotheses advanced.[8] More concern was given to the process of model formulation in terms of the existence and regularity of analytical solutions. The importance of primitive behavioral assumptions was also recognized. Applications of models based upon these theoretical foundations and investigations of their comparative statics seemed to represent the primary focus of the profession in the period following W. W. II.

More recently, research endeavors have moved into areas that require models which represent departures from the standard neoclassical theory. These directions (previously alluded to in another context) have raised some perplexing methodological issues--particularly as compared to the fairly comfortable position afforded by the umbrella of neoclassical theory. In brief, theoretical underpinnings of the quality of those provided by the neoclassical theory were either unavailable or quite demanding in terms of the rigor involved in the deductive arguments required. The choices open to the applied researcher were then to restrict the investigations of some problems until adequate theoretical developments were forthcoming or to construct more descriptively oriented models--incorporating the accumulated knowledge where appropriate. The latter choice involves examining problems with an approach which in some respects represents a combination of the older empiricists orientation and the more recent deductive methods.[9]

A second historical observation of interest in providing a perspective for the remainder of the study is concerned with the origins of the simulation concept. On the basis of the above discussion of the systems approach the analogy to be drawn between simulation and other methods or investigating models is rather easily facilitated. To begin, it is clear that a principal concern of applied work with systems models involves problems connected with solutions. In fact, methods of obtaining solutions to more complex types of models are typically rather difficult. An attractive option for dealing with these problems is to experiment with the models. That is, perturb a subset of the independent variables--including the stochastic ones if appropriate--and observe the effects. Such tactics for investigating or searching for solutions in complex mathematical formulations are commonly known as Monte Carlo and/or numerical methods.[10]

Once this analogy is made it is apparent that computer simulation in connection with systems models represents a standard type of mathematical approach. This numerical approach to the solution of, or more generally, the investigation of systems models is clearly advantageous to actual experiments conducted on the subjects being modelled. The advantage, of course, is increased with the availability of high speed computers.

Scope and Objectives

Having dispensed with the orientation and some basic definitions we turn to the objectives and scope of the paper. Our major objective is to provide a heuristically based survey of the post-war developments in simulation and systems analysis within Agricultural Economics. Given this objective it is important not only to summarize applications in Agricultural Economics but also to provide a basis for evaluating these efforts.

The paper proceeds as follows. In section II the general concept of a system is developed. In addition to some basic definitions, the section includes a discussion of the advantages and basis for various types of systems. In addition to these basic types of systems there are some important attributes of systems which have consequences for model specification and simulation.

These include concepts of components and decomposition, ideas of complex interactive models and alternative forms of time dependence.

Section III is devoted to a discussion of alternative methods and purposes for simulating systems models. The section includes a discussion of descriptive or behavioral, forecasting, and decision applications. In laying out these alternative purposes for simulating and the corresponding simulation procedures a number of comments are made with regard to the information potential of the various methods advanced. Also included in this section is a discussion on special computer simulation languages. Section IV concentrates on the construction and validation of economic systems models. Here we shall argue that these aspects of the systems approach have been largely neglected or handled mechanically in Agricultural Economics. Aspects of model specification, parameter estimation and model validation or verification are also examined in this section.

In section V we review applications in Agricultural Economics over the post-war period. These reviews include tabular surveys as well as some comments on the results and methods employed. The review is subject oriented and includes the following: gaming, firm and process models, market models, aggregate models, resource models, economic development and natural resource models. Although the classification is admittedly arbitrary it appears to serve the general purpose of providing a basis for conveniently cataloging the applications.

The survey concludes with a critical appraisal of the Agricultural Economics work in section VI. This critique includes an assessment of the noteworthy findings and contributions to systems analysis methods. In concluding we summarize the findings of the survey, treat some promising developments which are being prompted by the widening use of the systems approach and finally draw attention to some methodological issues arising from the application of systems analysis and simulation as a research tool.

II. SYSTEMS AND SYSTEMS ANALYSIS

Systems and Related Concepts

Recall from the previous section that elements and relations are the primitive or basic notions on which the concept of a system is defined. Before proceeding to the discussion of systems, systems analysis and simulation in the Agricultural Economics literature it will be useful to sharpen this general definitional framework. The structure to be added to this definitional "system" will provide a basis for the organization of the survey and hopefully some revealing insights as to the extent to which "systems thinking" (Churchman, 1968) has directly and indirectly influenced the efforts of the profession.

For purposes of this discussion and the subsequent investigations of the work of Agricultural Economists, some notational conventions are useful. To begin, we assume that the elements of a system can be represented by $X_1, X_2, \ldots, X_n, Y_1, Y_2, \ldots, Y_m$. In keeping with the current level of generality we note that these elements may be concrete and measurable or abstract in nature. Although many other designations are possible, it is useful to think in terms of the elements $X = \{X_1, X_2, \ldots, X_n\}$ as inputs and $\underline{Y} = \{Y_1, Y_2, \ldots, Y_m\}$ as outputs. This classification of elements is convenient for economic systems because they are typically perceived as on-going processes (Orcutt, 1960), (Naylor, 1971). The relations defining the system are denoted by $R = \{R_1, R_2, \ldots,$

$R_\ell\}$ and are to be viewed as providing the connections between the elements.[11]

Given this representation of elements and relations, the notion of a system can be schematically characterized as follows:

$$Y = \{Y_1, Y_2, \ldots, Y_m \mid X \text{ and } R\}$$

This representation is convenient for introducing the idea of a state. If systems represent on-going processes or collections of them, then it is useful to think of systems in terms of their relevant properties at any particular moment in time.[12] As the properties which are obviously defined on the basis of the elements, relations, or some combination of them--are unlimited the qualifier is of value in describing the system. That is, the properties define the state of the system. On the basis of this added qualifier we can now view systems in terms of their movements between states, their activity within states and the process by which they move from state to state.[13] It goes without saying that questions regarding these types of statements about economic systems have provided a basis for much of the theoretical and empirical work to date.

A second idea which has important applications in systems concepts as applied to economic problems involves the classification of elements. As economics is a behavioral science, an important aspect of the study of economic systems is connected with concepts of causality. It is, therefore, convenient to partition the elements into those which effect but are not affected by the system and those which both effect and are affected by the system. The former types of elements are said to provide the environment for the system (Ackoff, 1971) or to isolate the exogenous systems inputs (Orcutt, 1960). These conditioning elements suggest a rather general schematic representation, since they may be either X's or Y's and may condition both inputs and outputs. In particular if we let $X_1, \ldots, X_r$ $(r \leq n)$ and $Y_1, \ldots, Y_s$ $(s \leq m)$ and denote the conditioning or environmental elements and partition R into $R_1, R_2, \ldots R_6$ subsets (possible not proper) the extended representation becomes:

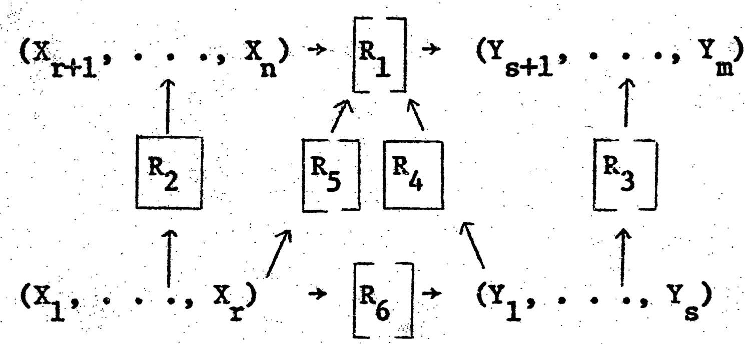

Figure 1

As indicated by the figure, these environmental elements may condition the basic input-output specification through the input and output elements, the relations, or a separate relation R_6.

From the above discussion it should be clear that the concept of a system is indeed quite general, even as applied to the input-output type framework which has been used to characterize many economic systems. Such general representations provide the basis for systems modelling and analysis. Before proceeding to special aspects of these systems models--specifically their construction, analysis and validity--it is worthwhile to investigate some systems classifications. These classifications are useful both in terms of understanding and constructing systems models and in evaluating the models in terms of the systems they are designed to represent.

Systems Classifications

There are quite naturally numerous approaches to classifying systems (Ackoff, 1971), (McMillan and Gonzales, 1965). The purpose of this discussion is modest in the sense that the classifications suggested are not complete. Instead they are simply those which seem to have been useful in model building for studying problems or systems of interest within Agricultural Economics. The natural alternatives for classifying systems are in terms of the relations R, the types of elements, Y and X, and a state dimension t. Although we shall have more to say about theory and its role in systems analysis when the topic of model construction is officially examined, it is important to recognize that most classifications used in economics research are associated with the underlying theory (Naylor, 1971).

Systems used in economic reasoning typically fall into three categories. The first and possibly most common of these categories refers to the state dimension of the system and partitions the set of systems representations into static and dynamic models. Static systems models abstract from time while dynamic systems models are ones in which time enters in an intergral way. As has been elaborately argued elsewhere, the more recent concern with dynamic problems in economics and in particular modelling of dynamic systems has given rise to the use of many types of simulations (Naylor, 1971), (Shubik, 1960).

A second useful possibility for classifying systems representations involves stochastic and non-stochastic models. As usually perceived for purposes of model building, the stochastic nature of systems can arise from the existence of truly random elements in the system or from a lack of competeness with respect to the conceptualization of the system, i.e., Classical or Bayesian ideas as to the origin of probabilistic statements (Zellner, 1971).

The former case might include models of chemical reactions which are intrinsically unstable, gaming models and the like, while the latter situation could be represented by our usual conceptualizations of economic systems in which little attention is given to institutions and non-economic variables which are thought to have an important but unsystematic influence on the relations and elements. As a practical matter, the stochastic nature of models based upon systems presumed to be either stochastic or non-stochastic tends to involve the parameters defining the relations and the error terms specified as elements. That is, since models are by nature simplifications, it is not uncommon to have stochastic models of non-stochastic systems.

The last of the three classifications of systems deserving of attention involves systems which are historical and non-historical. In discussing this classification of systems it is important to distinguish between the early use of the terminology and that for which it has been more recently used. Early efforts in systems and simulation analysis tended to be oriented towards attempts to conceptualize systems and construct models which could be employed to reproduce historical sequences of events (Forrester, 1961). This was for example the case with early treatments of macroeconomic systems and models (Howrey and Kelejian, 1969) and in early behaviorally oriented models of the firm (Cohen and Cyert, 1965), (Shubik, 1960). The distinction in this case typically was with respect to whether historical values of environmental elements were posited in terms of a probabilistic characterization or simply used as an observed sequence (Churchman, 1960). More recently, the categorization seems to have been applied to distinguish between systems which are and are not evolutionary. Historical systems in the sense that they include explanations for changes in structure between states are adaptive and, therefore, evolutionary (Ackoff, 1971). Non-historical models are those for which the structure has captured in R and the element designations are presumed to be time invariant.

Some Other Special Attributes of Systems

The system attributes which are mentioned in this section are characteristics in the sense that they follow from special properties of the elements, relations and states. They are treated separately since they are somewhat less general in terms of their implications for the functioning of the systems and they have particular importance to the practical aspects of model construction. The first of these attributes concerns the idea of a systems component. Systems components are subsets of relations, elements and states which can be taken to have a particular function. For example, industrial firms can be thought of as having marketing, management and production components; farm production units can be viewed as being composed of crop and livestock components; development models can be taken to have industrial and agricultural components and so on.[14] The usefulness of the idea of a system component is largely derived from the simplifying possibilities it presents. if understanding of a system is based on gaining knowledge of its components, then there are substantial advantages of designing research strategies for investigating the system and presenting the results of research efforts in a meaningful and effective fashion (Babb, 1964). In short, the possibility of viewing a systems as sets of components facilitates a modular or building block approach to their analysis.

A related advantage of the systems components concept concerns the possibility of decomposition. Formal ideas of decomposition are quite important in economic systems. Since many models of economic systems are used for planning purposes, it is important to isolate particular components which can be relied upon to perform in a specified manner. System decomposability of a system is, of course, a matter of degree. At one extreme the subsystems are completely self contained, while at the other the components are not functionally identifiable. Situations in which decomposition appears to have considerable promise exist in national planning models and in intertemporal models in which myopic behavior is assumed or shown to be optimal on the basis of the behavioral postulates on which the system is based.

The second systems attribute to which we wish to draw attention also has major implications for model building and, more generally, the study of systems. Specifically, it is concerned with the method by which systems are viewed. To begin, it should be clear from our previous discussion that the concept of a system can embrace entities which are extraordinarily complex. In fact, an individual's perception of a complex system may itself be thought of as a model. A perception of a system is, therefore, just the image of the system as registered in the impressions of the individual researcher.

In the presence of this observation the distinction between systems and systems models becomes rather vague. For example, suppose a marketing researcher sets out to study the system from which an observed pattern of behavior emanates, say brand preferences. The initial impression of the system may be rather simple as opposed to the one which is eventually modelled for research purposes. In addition, the process of moving to the more complex model is likely to involve some interaction between the individual and the system. As this interaction occurs, the image of the system may be thought to be expanded in terms of detail or even altered in terms of its orientation. Whatever the situation, the fact that the perception of the system changes as it is investigated suggests that systems models and concepts of systems have some type of relative relationship to each other.

Models in which such a relationship has been explicitly recognized are called complex and interactive (Kuehn, 1962). The consequences of this observation are extremely far reaching and embrace ideas of adaptive systems, adaptive models and various types of learning hypotheses.[15]

The third and last attribute of systems concerns the idea of feedback. The term feedback as used in describing systems and in systems analysis has many usages. Central to the idea is the notion of information flows. These information flows may occur between model builders and the system (as mentioned immediately above), between various states or components of the system and the like. The notion of feedback is, of course, not new. It could be argued that economic theory--if viewed in association with the development of institutions or empirical confrontation--has evolved by such a process. Types of feedback which exist within systems are quite important in influencing the approach to their study. This is true whether we regard the process along more technical lines in terms of various forms of dynamic relations or, more generally, in terms of an evolving or evolutionary concept of systems.

As we move to the next section, it is important to summarize observations which have been made in regard to the notion of a system. Economic systems may have all of the characteristics or only a few. The characteristics are not specified as a basis for providing a classification system for systems. This has been previously attempted for general systems (Ackoff, 1971). Instead we use these characteristics to enrich the concept of a system as it relates specifically to economics. By drawing on some characteristics of more traditional economic models and relating them to the systems idea, we hope to have provided some insights for the concept of a system as applied to economic problems. We proceed now rather naturally to the discussion of possibilities for modelling and simulating systems.

III. SIMULATION OF SYSTEMS MODELS

Models and Simulation--An Overview

As previously defined, a model is an impression or image of a system. These facsimilies of systems can, of course, take many forms--ranging from physical analogues of the type constructed for early investigations of macroeconomic systems to more formal mathematical representations and computer programs. In Agricultural Economics most models of systems are specified mathematically and/or in the form of computer programs. As a consequence, our discussion of simulation will be presented in the context of these models. It will be important, however, to keep in mind that this is a fairly arbitrary restriction on the types of models which might be discussed in connection with a more general treatment of simulation.

The motivation for constructing models is, rather clearly, the investigation of the corresponding systems. That is, models can be studied as a basis for providing information or knowledge about systems. These models usually can be viewed as descriptive or behavioral, forecasting, and decision models (or some combination thereof). Decision models provide information as to how to improve particular systems, behavioral or descriptive models give insights into the forces motivating and suggest the basics for understanding the functioning of systems, and etc.. In addition to providing insights as to the operating nature of systems, information obtained from the study of models can be used to evaluate the models themselves and perhaps alter them to correspond to a more enlightened or comprehensive view of systems.

One method for studying models of systems is through experimentation. As our definitions of models and systems would suggest, these experiments can be conducted with regard to alternative specifications of relations, elements and states. For example, an experiment frequently conducted with economic systems involves the generation of output elements on the basis of prespecified input elements and a hypothesized set of relations and environmental elements. The important aspect of the experimental method as it relates to systems and systems models is, of course, the possibility it presents in terms of control. That is, by controlling various parts of models and conducting experiments with them, useful information can be obtained with regard to both the internal functioning of the model and the system under study.[16]

The process of experimenting with systems models may be referred to as simulation. Computer simulations are then experiments with systems models that can or have been represented as computer programs. To quote a modern definition of computer simulation as it relates to economic systems, it is "a numerical technique for conducting experiments with certain types of mathematical models which describe the behavior of a complex system on a digital computer over extended periods of time" (Naylor, 1971, p. 2). Once it is recognized that simulations of systems are just experiments with systems models, some useful results can be developed from related concepts of experimental design. These results, of course, reflect the idea that experiments with models can be designed with efficient strategies in regard to the types and quality of information generated and are, therefore, of importance in both the design of simulations and in the interpretation of the information generated by the process. Hence, it will be necessary to keep the following general types of observations in mind when reviewing the reported simulations and evaluating the associated results.

First note that since simulations can be identified with the process of experimentation it follows that considerable attention should be given their stochastic nature--a characteristic of systems which was singled out in the previous section. Recall from this discussion that systems can be stochastic or non-stochastic and that if stochastic, the randomness can enter through the existence of stochastic elements, relations or both. The same is, of course, true with models. However, since models are by nature simplifications of systems they may be viewed as stochastic even when the systems they are presumed to represent are not. Omitted or misspecified relations and elements are in these circumstances assumed to add to or give rise to the stochastic components of the models. If the error terms in the models result from such considerations, then it is apparent that the method by which they are characterized is of substantial importance in planning and evaluating simulations.

A second and related area of concern is associated with ideas of experimental design. In the simulation of economic systems it is frequently true that one or more types of outcomes are of interest. If these outcomes are given by structural relationships with other elements in the system, then they can be viewed as composing a type of response surface. Questions of the reliability with which the surface must be identified, the range over which the surface is to be investigated, and elements of the system which are under control then suggest some rather fundamental considerations. In particular, how and what simulations of the model should be conducted.

A third observation which has relevance to the use of simulation in studying systems is directly related to the complexity of the models. As the complexity of systems models increases, it is natural to presume that they more adequately characterize the system. However, it is also generally true that as the complexity of systems models increases it becomes more difficult to design and conduct useful simulations--useful in the sense of providing information as to the accuracy with which the model has characterized the system and the possibility of identifying the applicability of the information generated by the simulation with the purpose for which the experiment was intended. These considerations, of course, suggest that as the systems become more complex greater attention must be given to the design of simulations since the possibility of being mislead or misinterpreting simulated results is likely to increase with model complexity. Although this dimension of the problem of simulation experiment design is as yet unsettled, it has a substantial impact upon the importance which can be attached to many of the simulation results which have been obtained by Agricultural Economists.

In the remainder of this section on simulation of systems models we investigate the topic with regard to particular types of purposes. In keeping with our attempt at providing a general basis for evaluating the work in Agricultural Economics we will categorize these types of simulation experiments by objective rather than by type of application. Specifically, simulations for descriptive or behavioral, forecasting, and decision purposes are examined. The section closes with a brief examination of the special languages for computer simulations. These languages are viewed with respect to the types of models for which they are intended and possible computational economies.

Simulation of Behavioral or Descriptive Systems

Many of the models of economics systems are behavioral or descriptive in nature. Although the concept of behavioralism is a general one and indicative of most models attempting to describe individuals or groups, the term as it relates to types of economic systems is identified principally with the works of Orcutt (1960), Shubik (1960) and Clarkson and Simon

(1960). The first popular and rather complete synthesis of the behavioral systems approach was firm oriented, (Cohen and Cyert, 1965) and (Cyert and March, 1963). The approach embodied in these writings appears to have had a substantial effect in Agricultural Economics. A related development of the systems approach (Forrester, 1961) has also been influencial but probably not so much as the above mentioned works. This may be partly due to some programming language difficulties and the completeness of the break with neoclassical theory. The important attribute of behavioral or descriptive models as they relate to research on economic systems is that they are constructed upon concepts which are less primitive than those say of neoclassical theory. For example, firm models rather than being cast in a profit maximizing mode with simplifying assumptions as to maximizing motives and/or abstract characterizations of the production process, are conceived as more complex organizations in behavioral systems of the Cyert and March type. In such models we find, for instance, decomposition of firm management, marketing, and production functions. Models are then constructed to approximate the system represented by the firm with the functioning of the models contingent upon observed or hypothesized behavioral types of conditions. To illustrate, if the firm uses a break-even type rule of thumb in connection with a particular process, this type of condition would be built into such systems models.

Advantages of behavioral or descriptive models are, as the above illustation would suggest, in terms of their flexibility. That is the formulation of systems models is viewed in a less restricted sense than if they were guided strictly by neoclassical theory (Cyert and March, 1963 and Shubik, 1960). The adaptation of such models to Agricultural Economics is possibly due to the pragmatic orientation which was discussed in section I. Whatever the motivation for adaptation, these models are highly flexible and capable of permitting the quantification of many aspects of individual firm and industry behavior which are ruled out by more abstract and primitive models based upon neoclassical theory (Naylor, et al., 1967). As we subsequently indicate, the accommodating characteristics of these exploratory types of models have some very definite implications for their simulation (Box, 1957).

If the general objective of descriptive or behavioral analysis of systems is to learn or explore related systems, then some rather broad guidelines can be set down to govern the process. The nexus of these guidelines is the simple idea that successful or efficient methods of learning demand the full use of prior knowledge in proposing useful systems as well as good experimental strategies for gathering evidence which can be of use in the perpetual process of syntheses, conjecture, and testing (Hunter and Naylor, 1970). Hence, even in the examination of behavioral or descriptive models, questions of the design of experiments are of fundamental importance. The systems approach provides a useful framework within which to conduct these explorations because of the facility that related models have for handling the various types of prior and experimentally generated information.

Aspects of experimental design which relate to the types of information typically obtained from standard computer simulations have been summarized elsewhere (Hunter and Naylor, 1970), (Hufschmidt, 1966), (Hill and Hunter, 1966) and (Naylor, et al., 1967). As it turns out, simulation experiments rest upon the same types of considerations (involved in the choice of an experimental design) as do similar problems in classical experimental design (Cochran and Cox, 1957), (Box, 1954, 1957) and (Box and Hunter 1959). Factors are input elements, the relations connecting inputs and outputs are unknown but of a hypothesized functional form and the inputs determine the response surface. The environmental variables may be assumed to be included if the system is conditioned by them and are treated as additive error terms in a large number of experimental (additive) designs of systems models. Given this conceptualization experimental design results can be generally applied in simulating models of systems. That is, questions regarding appropriate design (full factorial, fractional factorial, rotatable, response surface, etc.) are largely answered in the above mentioned statistical literature.

Although these design considerations are mainly borrowed from the classical statistical literature, there are some special problems or contingencies which occur as a result of the nature of the computer type experiments. These include problems related to: (i) sample size, (ii) factor numbers, (iii) multiple responses, and (iv) convergence in the context of adaptive and optimizing experiments (Naylor, 1971). The problem of sample size is simply that of determining appropriate number of observations required to guarantee a prespecified level of statistical precision (Handscomb, 1969). As "costs" involved in obtaining and analyzing observations in such experiments are quite different than those in more classical situations, the trade-offs with reliability (or statistical precision) become a major concern. In addition, more elegant methods of variance reduction become applicable (Hammersley and Handscomb, 1964).

The second problem--that of too many factors--is most relevant in large and complex models of systems. This is not in principal a difficulty peculiar to simulation. It was, for instance, a major force in the development of partial factorial designs. The problem, however, has special bearing upon simulation experiments because of the ambitious nature of the models frequently employed. Although large scale and relatively inexpensive computers to some extent alleviate this problem, it remains an area of concern. As will be clear in the survey of the empirical results, this problem is frequently neglected in the construction of simulation models.

A related problem, on the output side of experimental models, is that of multiple response surfaces. The difficulty usually comes about since the nature of the systems examined require us to view many different responses in a particular experiment. A possible solution to such problems is, of course, to construct indices of the numerous response variables which require observation (Fromm, 1968). This procedure, however, has the major limitation of implicitly incorporating the idea of defining a utility function over the outcome space. In the absence of such arbitrary procedures, there appears to remain a substantial gap in the theory at this stage. In particular, it is not clear how to investigate such surfaces or what properties are exhibited by results obtained from the various partial methods of handling such problems. A reasonable conjecture would be that they involve the same types of indexing problems which were mentioned above. Again, as was the case with the previous problem, these considerations or contingencies suggest some very pronounced types of practical limitations. They are simply that we can build larger and more complex models than we know how to efficiently experiment with or examine.

An issue related to problems of multiple responses involves the complexity with which the inputs are related to the outputs. Again, we are likely to find ourselves in situations in which the models as constructed--without adequate thought as to how they are to be experimented with--are very difficult to adequately analyze. If the relations connecting the inputs are nonlinear in the factors, polynomial approximations may be advantageously employed. However, for more complex types of nonlinearities questions of designing and conducting experiments to investigate models of systems remain unanswered (Howrey and Kelegian, 1969, Naylor, 1971 and Rausser and Johnson, 1972).

Problems of convergence in designing experiments to investigate response surfaces are by nature extremely difficult. These problems occur in the context of simulation experiments which are of an optimizing nature. From the standpoint of behavioral models such problems arise in the development of improving models of systems. That is, suppose we begin with a mode which is suspected to require improvement if it is to adequately represent the system to which it corresponds. One procedure for improving the model would then be to experiment with it, analyze the data and adjust the model in whatever fashion that might be suggested. The problem of designing experiments for this type of adaptive model building exercise is very difficult (Naylor, 1971 and Zellner, 1971). However, if a criteria by which the model is to be evaluated can be specified and the problem is of manageable dimensions, such adaptive experimental procedures can be viewed in the context of adaptive control theory. We shall return to this issue in section VI.

We close this discussion of behavioral or descriptive models with the following general observations. Such models represent an important first step in the search for knowledge about systems. Simulation is obviously a useful method of gaining experimental knowledge about such systems. The fact that simulations are experiments, however, raises some interesting questions with regard to experimental design. Although these problems are not peculiar to behavioral models, they do suggest that such considerations should be observed when constructing models of systems. In the survey of simulation models in Agricultural Economics it will be apparent that these attributes of simulation and modelling have generally not received the attention they deserve. The sense in which this omission detracts from the results should be clear from the previous discussion.

Forecasting and Prediction

Forecasting and prediction are important functions for which models of systems in Agricultural Economics are employed. That is, systems models are constructed for generating price movements, predicting changes in geographical location, forecasting changes in characteristics of agricultural firms and the like. The process of obtaining forecasts from these systems models is, of course, simulation. Experimental design questions are again appropriate, since questions of designing experiments with the model so that reasonable forecasting criteria are met is a basic problem in connection with such simulations. More specifically, when we base forecasts on simulations of systems it is important to have some idea as to their reliability and sampling characteristics.

Early uses of simulation for forecasting in Agricultural Economics and elsewhere tended to give little consideration to these problems. More recently in a few places these issues have been explicitly treated in the construction of systems models and in the design of simulation experiments (Sasser, *et al.*, 1967, Naylor, *et al.*, 1969). The experimental design problem which is associated with simulating systems models in this context is associated with the response surface identification methods and difficulties mentioned earlier. That is, models of economic systems which are used for forecasting purposes are typically concerned with projections of output variables. As these output variables form the response surface, it is necessary to know the statistical properties of this surface if the forecasts are to be evaluated. We will not, however, reiterate our previous discussion of these methods at this point. The difficulties of optimal design and dimensionality obviously apply as well to forecasting and prediction. Instead, we raise a related issue which has special relevance to the use of simulation in this context. This issue is concerned with whether or not analytical or simulation methods should be applied in utilizing models for forecasting purposes. Although we take this question up in more detail in connection with model verification, the relevance it has to the forecasting problem demands some comment at this point.

Given a model representing a system and an objective of forecasting or predicting the behavior of the system there are essentially two procedures available. We can, as previously indicated, simulate or experiment with the system and obtain forecasts based on these simulations or analytically derive the reduced form and make such forecasts on the basis of more standard statistical procedures. The latter is clearly the more desirable when the model is sufficiently simple. That is, when we can, it is advisable to take advantage of the standard results in statistical theory (Howrey and Kelejian, 1969 and Rausser and Johnson, 1972). As the models become more complex, however, and derived reduced forms or approximations thereof become more difficult to obtain and less accurate as representations of the structure, it seems intuitively obvious that simulation becomes more desirable. Such is unfortunately not the case, for the same types of model characteristics which give rise to the analytical difficulties turn out to detract from initial impressions on the attractiveness of simulated forecasts. The problem is simply one in which we may obtain numbers by simulation but cannot determine or ascertain their correspondence with the system. In fact, it has been shown in the case of nonlinear econometric models that simulated forecasts diverge systematically from those which should be rightfully obtained from the system (Howrey and Kelejian, 1969 and Haitovsky and Wallace, 1972). These results do not suggest that simulation is inappropriate as a forecasting tool. They instead suggest that great care should be taken in interpreting simulated forecasts. Moreover, unless these forecasts are based upon experimental designs which provide some indication of the reliability with which the response surface can be determined there is little in the way of a convincing rationale for assuming that they have desirable forecasting properties.

Decision Applications

Decision problems in economic systems have some fairly universally accepted sets of components. More specifically, we usually think of such problems as having controllable variables or factors, objective functions, and some types of structure which relates the controllable and uncontrollable (input) variables to output variables (Fox, *et al.*, 1966). Simulation of systems models for this purpose again involves questions of experimental design. First, if we assume that the model adequately characterizes the economic system which it is designed to represent, it is clear that simulation or experimental investigations of the model should be designed to converge to an optimal solution or at least proceed in an optimizing direction. In this context simulation experiments become very closely tied to Monte Carlo or numerical methods of solving the optimization problems implicit in the policy models. This suggests that considerable thought should be given to the formal analytical properties of the systems model as well as to the design of the experiments intended to lead to or approximate the optimal solution (Dorfman, 1965 and Rausser and Johnson, 1972).

Some positive elements of these prescriptions with regard to how experiments should be designed in policy models are lost, however, when we recall that the models are but approximations of the systems being investigated. As a result, we may think of the entire model construction and optimization process as an experiment vis-a-vis the system. This suggests, as indicated previously, that it is more proper to think of these problems in a nested sense--numerical optimization procedures applied to solve problems which are themselves designed to simulate systems. In this more general context we are again thinking in terms of a problem in adaptive control theory. Such problems are far from tractable for systems of the size of many models in Agricultural Economics. It is, however, quite useful to keep this framework in mind since it may be of considerable use in suggesting general guidelines for policy simulations.

Special Simulation Languages

Simulation languages are special or problem oriented computer languages which are designed to facilitate the programming and analysis of simulation models. Our purpose in this section is to briefly discuss the considerations involved in formulating such languages and to relate them to types of systems models as well as some more generally understood concepts in computer programming. The brevity of the discussion results mainly from availability of current and very good survey papers on this subject which exist elsewhere (Gordon, 1969), (Krasnow and Merikallio, 1964) and (Kiviat, 1969). We include this token discussion of simulation languages, therefore, largely to give completeness to this section on simulation of systems models. Although these languages have not been particularly widely used in Agricultural Economics, a discussion of simulation of systems models would be incomplete without at least a limited investigation of these special purpose languages.

Before going into detail in regard to the functioning of the languages, it may be helpful to review some basic concepts. 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. To continue, a compiler is a program which accepts statements which are written in complex and high level languages and converts them to basic machine language. Most compilers are problem oriented and, thus, are different from machine languages and assembly languages. That is, they are composed of language symbols and operations which are required by a special type of problem. COBAL is, for instance, a problem oriented language which is convenient for application to types of problems involved in the data handling aspects of Accounting. The compiler then translates these more structured languages into basic machine languages (via what is called an object deck) so that the communication with the computer is complete. Finally, simulation programming languages are just special types of problem orientated 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 and (Krasnow and Merikallio, 1964).

As these languages have developed in connection with particular types of systems models and are designed to facilitate experiments with such models it is natural to conclude that their principal features are:

1. They provide data representations that permit straightforward and efficient modelling.

2. They permit the facile portrayal and reproduction of dynamics within modelling systems.

3. They are orientated to the study of stochastic systems, that is, they contain procedures for the generation and analysis of random variables, and time series.

Aside from the se general features, even the more general of the simulation programming languages are problem orientated. For example, SIMSCRIPT II is an event orientated language and, therefore, useful in simulating systems which can be viewed as sequences of events with particular types of attributes. Various types of management and behavioral problems, therefore, lend themselves to simulations with this special programming language (Markowitz, et al., 1963). DYNAMO is a special purpose language which is orientated toward the study (over time) of closed systems of continuous variables in which the broad characteristics of information feedback within the system are important attributes in determining dynamic performance. This is the language that developed in connection with the industrial dynamics or behavioral modelling of (Jay Forrester, 1961). SIMULATE developed by (Holt, et al., 1964), is concerned with capturing those parameters and (decision variables which are critical in the determination of model stability.

Continuing with this sample list of special purpose languages, CSL is an activity orientated language (I.B.M., 1966). This language is useful for simulating models based upon systems involving waiting line problems, sequencing of events in an efficient manner, etc.. Finally, GPSS is a transaction orientated language, (I.B.M., 1966 a). It is closely related to CSL in that it can be applied to simulate problems involving efficient processing of individuals, ships, cars, etc.

In summary, these special purpose computer languages permit or facilitate easier simulation of various types of systems models. They are somewhat more removed from the basic languages than the common scientific computer languages, e.g., 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). Hence, unless substantial amounts of simulation of a particular type are anticipated or the simulation problems require very specialized language features, investment in such languages for applied researchers do not appear to be profitable.

IV. CONSTRUCTION AND VALIDATION OF ECONOMIC MODELS

In the previous three sections we have provided definitions of systems, systems models, systems analysis and simulation. We have also discussed the association of simulation with experimentation. In this section some aspects of the construction and evaluation or validation of systems models are considered. It turns out, not surprisingly, that the guidelines developed for model construction and evaluation have a great deal to do with types of systems being investigated and with the experimental methods to be employed in studying them.

The section proceeds with a discussion of model construction. This discussion emphasizes the distinction between more Classical models of economic systems models and those which are formulated upon the basis of less primitive assumptions and normative concepts. Having discussed model construction, we turn to parameter estimation. In the case of systems model estimation this, of course, leads to an investigation of estimation methods which can adapt to alternative types of prior and sample information. Lastly the concept of model validation is investigated.

Model Specification or Construction

The fundamental questions arising in model construction are, of course, methodological in nature. That is, models are studied as a basis for understanding systems. They therefore, reflect how we perceive the world as well as the method by which such knowledge is generated. The two basic methods by which knowledge is generated are inductive and deductive reasoning. The various methodologies positivism, empiricism, experimentalism, etc., of course, incorporate these methods in varying degrees (Johnson and Zerby, 1972). However, rather than indulge in the philisophical questions associated with the search for knowledge, we concentrate on issues which are more practical in nature.

Agricultural Economists are in general inclined to follow a research approach which involves the so called scientific method. As applied to economic systems this method entails four basic steps: (1) observation of the system, (2) formulation of models designed to explain the observations on the system, (3) the performance of experiments designed to examine the validity of the model,[17] and; (4) explanation and/or prediction of the behavior of the system on the basis of the implications of these models. It is easily seen that this method encompasses the systems analysis approach. What then is the purpose of this discussion on model construction? It is quite simply that, even though the scientific method is generally employed, differing emphasis on the four steps has substantial implications with respect to generality with which the models apply. More specifically, as researchers investigating applied problems we are typically involved in a type of compromise in model formulation. On one hand, it is clear that if the models could be formulated on the basis of some primitive and generally accepted normative and physical concepts, then the results would have wider acceptability. That is, the structure of the mathematical representation would be deduced upon accepted normative propositions and upon generally believable types of technical relationships. Under these circumstances, models are more easily tested and usually less complex structurally.

At the other end of the spectrum is the completely descriptive or more properly behavioral model--the type employed in macro or aggregate economics. These models on a comparative basis are easily formulated because the process is simply one of observing the system and specifying (in simplified form) the behavioral and other structural relations. The principal difficulty with these models is that the tests they afford are not as informative as they at first appear. If the behavioral hypotheses are not refined, then empirical tests are reduced in importance by virture of the large number of competing or alternative hypotheses.

As a consequence of these two types of considerations, the process of model formulation for investigating economic systems imposes some fairly artistic types of demands upon the researcher. To complicate matters even further, the previous discussion of model simulation has shown there are decided operational advantages in developing systems models which are of reasonable dimensions. The upshot of these modelling difficulties is that we find model construction proceeding on a trial and error basis--typically beginning toward one end or the other of the above mentioned spectrum and proceeding to some middle ground. Behavioralists are continually refining models so as to adapt them to more general types of systems--in a sense they are attempting to reduce the behavioral models to some type of more primitive conditions 'using guidelines from economic theory'. Alternatively, the more normatively orientated model builders tend to become dissatisfied with restrictive structures and attempt to make models more applicable by making them more realistic, i.e., specializing them.

The Agricultural Economics literature indicates that the incorporation of systems ideas has substantially influenced modelling procedures. Moreover, trade-offs implicit in the examination of the generality of behavioral models turn out to be subjects over which there is and will continue to be considerable controversy. Models are just hopefully persuasive stories. As researchers we should attempt to make them as acceptable as possible--by taking advantage of the received knowledge as to how the systems in question operate and any appropriate normative propositions. It is also apparent from the simulation or experimentation discussion that there are strong reasons for attempting to develop simplified models which can answer the questions posed in connection with the system.

Parameter Estimation

Parameters of structures of systems models are estimated by a number of different methods. These range from econometric methods applied to linear equation systems (Goldberger, 1964) to those which tend to disregard sample or past observations on the systems (Forrester, 1961). In the former situation the process of inference about the parameters is Classical in nature. That is, a maintained hypothesis is specified and sample information (whether passively generated or of an experimental nature) is utilized to obtain estimates of the structural parameters and their sampling distributions. The latter or Forrester approach rejects available sample data as containing little or no correct information about the structure.

Parameter estimates are introduced on a subjective basis or calculated using technical or engineering types of relationships. In the first case we find the systems modellers relying heavily upon Classical types of econometric methods while in the second case they reject the data either because (i) they are as yet not sure of the appropriate data (Forrester, 1968) or (ii) of the types of available economic data (due to the possible type sampling process generating such data) or (iii) to suspected structural change.

In addition to differences which are due to assumed sources of useful information, parameter estimation methods for systems models are frequently sequential or iterative in nature. That is, it is not uncommon to find that the estimation process involves considerable pretesting of the structure.[18] Parameter estimates are, thus, obtained on the basis of sample or prior information and the performance of the model representation for the system. In view of the diversity of the estimation methods both in terms of information sources and the possible iterative procedures involved, a rather general framework is needed for evaluating this aspect of the agricultural applications of the systems and simulation approach. It turns out that such a framework is available and although not always practical for envisioned applications it is quite useful in providing a proper perspective for estimation work currently underway. Such a perspective can provide a basis for assessing the advantages and limitations of the past work using the systems and simulation approach as well as provide some insights as to possible future developments.

In developing the framework for viewing estimation in systems models the problem of reconciling the use of alternative data sources must be considered. The framework involving nondata alternatives and apparently disparate estimation procedures is Bayesian in nature. That is, we systematically combine the sample information with subjectively held ideas as to parameter distributions to obtain estimates of the structure (Zellner, 1971). The data and nondata orientated approaches are then essentially the same with the difference a matter of the certainty with which the subjective estimates of the parameters are held.

In addition to its appeal for the data source problem the Bayesian framework is sufficiently general to provide a rationale for the iterative types of estimation procedures which are frequently encountered in the estimation of parameters for systems models. Given the selection of a particular model or representation of a system on the basis of available data or information, Classical inference procedures are violated if the same data or information is reused to estimate the parameters and investigate their reliability. In most applied situations such inconsistencies are not recognized or are justified on grounds of simplicity, avoidance of complications, and the substantial uncertainty associated with the decision of selecting the proper maintained hypothesis or model specification--the latter is typicallyy a result of the model specification alternatives mentioned earlier (Rausser and Johnson, 1972). In the context of these difficulties, the Bayesian approach would seem to be a viable basis for selecting among alternatives model specifications.[19] In fact, (Dhrymes, et al., 1972) has recently suggested that the Bayesian approach to the model selection problem, given the availability of informative prior distributions, 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, pp. 306-317) has provided a general outline of Bayesian procedures for comparing and choosing among models.

As a final observation on parameter estimation, we note that it may be useful to view the process adaptively. Many times systems models are constructed, estimated and simulated and while this process is occurring additional data on the structure becomes available. If the current structure representation is being used for policy purposes, then decisions taken on the basis of the model are also influencing the data generated by the system. In this case the model is truly adaptive. Although procedures for such models currently involve mathematical difficulties, it seems fairly clear that applied systems modelling is gravitating in this direction. Results which may be of some use in more formally grasping these ideas are contained in Prescott (1967, 1972), Zellner (1971) and Freebairn and Rausser (1972). As an additional source of complication, it is of interest to note that such arguments can be extended to suggest that the appropriate loss function for estimating the parameters is derived from the objective function of the systems model (Fisher, 1962).

Model Verification

Verification is a term which has been used in a number of ways in the model building and testing literature (Fishman and Kiviat, 1967) and (Van Horn, 1971). For purpose of the subsequent discussion the term is used in a broad sense, i.e., verifying a model is taken to describe the process of establishing it as an adequate characterization of the system it is designed to represent.[20] We are, therefore, focusing attention on the structural models themselves and only secondarily on such aspects as specific policy actions or results which might be implied on the basis of their use in a decision context.

The question of the appropriateness of a particular model for a system can be viewed from two standpoints. First, as is commonly done, the performance of the structure can be investigated in terms of its ability to reproduce or predict the variables in the system which are jointly or internally determined--elements of the set Y. When these types of investigations can be performed on a sampling basis, useful statistical results are available for evaluating particular models or for choosing between possible structural models. The second alternative for evaluating these models is suggested by the following observations. In building models of large and complex systems we are likely to employ specifications which are implied by various normative types of propositions. As much of the structural specification may follow from these propositions, it is natural to think in terms of attempting to assess their generality and thereby establish the validity of the model. This, of course, takes us afield from the popular positivistic approach to verification and into some gray and unexplored terrane (Johnson and Zerby, 1972).

The Classical Situation

When considered in connection with the variety of possible structural specifications (and methods of arriving at parameter values) for systems, the concept of verification becomes rather vague. In a Classical statistical sense the problem of verifying estimated relationships is in principle comparatively straightforward. Data required for an assumed structure are obtained through sampling the population, the parameters are estimated and inferences are made on the basis of the sampling distributions of the statistics obtained. Under sufficiently strong distributional assumptions the process of establishing the verifiability of the model is then a matter of examining its predictive power as well as agreement of the estimated parameters with qualitative restrictions suggested by the underlying theory.

Acceptable parameter values and accurate predictions are also the standards by which the verifiability of more general types of systems models are evaluated. However, the methods by which these properties of the structural models are examined are far from standard. It will be helpful, however, to keep the Classical problem in mind when viewing the circumstances under which systems models are constructed and the methods employed in verifying them.

Alternative Structural Specifications

The first and most obvious point of departure from the Classical situation is the possibility of alternative structural specifications. As the theoretical basis for systems analysis is far from complete, this is the usual situation (Heady, 1971, H. G. Johnson, 1951 and Thorbecke, 1971). The issue here involves 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 (in particular, Dhrymes, et al., 1972), these various criteria should be examined in context of a "Sherlock Holmes inference" approach. That is, a process of data analysis should be employed . . . "in which Sherlock the econometrician weaves together all bits of evidence into a plausible story" (Dhrymes, et al., 1971). This evaluation approach may involve attempts to determine both explanatory and predictive powers of the systems models.

Criteria advanced to examine the explanatory (non-predictive) power of systems models are usually 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 particular importance in this context. A number of such tests as well as other tests that might be employed to evaluate the explanatory power of systems models are indicated in Table 1. The suggested tests are, of course, most meaningful when parameters of the models have been systematically estimated from the observed series without recourse to auxiliary or artificial conditioning variables, e.g., time

Evaluation Criteria for Investigating the Explanatory and Predictive Power of Systems Models

	Explanatory	Predictive[d/]
Point Criteria	1) Coefficient of multiple determination[a/] – R^2 2) Durbin – Watson statistic[b/] 3) Graphical analysis of residuals 4) t statistic[b/] 5) Chi-square or F statistics[b/] 6) Aitchison – Silvey, [1958] test of a priori restrictions[b/] 7) Ramsey [1969] specification error tests[b/] a) omitted variable test b) functional form test c) simultaneous equation test d) heteroscedasticity test e) Chi-square 'goodness-of-fit' test for normality 8) Sample mean squared error[c/] (changes and levels) 9) Multiple comparisons of explained and sample data 10) Factor analysis of explained and sample data series 11) Information inaccuracy statistics for sample data	1) Mean forecast error[c/] (changes and levels) 2) Mean absolute forecast error[c/] (changes and levels) 3) Mean squared forecast error[c/] (changes and levels) 4) Any of the above relative to[c/] a) the level or variability of the predicted variable b) a measure of "acceptable" forecast error for alternative forecasting needs and horizons 5) t statistic[b/] 6) Chi-square or F statistics[b/] 7) Theil's inequality coefficient[e/] 8) Multiple comparisons of predicted and non-sample data series 9) Factor analysis of predicted and non-sample data series 10) Information inaccuracy statistics for non-sample data
Tracking Criteria	1) Number of sample turning points missed 2) Number of turning points falsely explained 3) Number of sample under – or over estimations 4) Rank correlation of Δy_t and Δy_t[f/] 5) Test of randomness for directional explanations 6) Test of randomness for explained turning points 7) Information theory statistics for sample data[g/]	1) Number of non-sample turning points missed 2) Number of turning points falsely predicted 3) Number of non-sample under – or over prediction 4) Rank correlation of $\Delta\hat{y}_n$ and Δy_n[f/] 5) Test of randomness for directional predictions 6) Test of randomness for predicted turning points 7) Information theory statistics for non-sample data[g/]
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	1) Bias and variance of forecast error 2) Errors in start-up position versus errors in predicted changes $(\Delta\hat{y}_n)$ 3) Comparison with various "Naive" forecasts 4) Comparison with "judgmental," "consensus," or other noneconometric forecasts
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	1) Comparison of power for predicted and non-sample data series 2) Spectral serial correlation test of structural or reduced form non-sample disturbances 3) Cross spectral statistics of relationships between predicted and actual non-sample values

a/ This measure, as is the case with 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, p. 38].

b/ These criteria represent only approximate small sample tests if the assumptions of the classical linear model (Ramsey [1969]) are not satisfied.

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

d/ This column is adapted from Dhrymes, et al., [1972].

e/ For a critical appraisal of this predictive criteria, see Jorgenson, et al., [1970].

f/ $\hat{y}_t$ denotes values of endogenous or state variables obtained from the model, y_t is the corresponding observation, t=1, . . ., T. For the prediction or non-sample observation period, n=T + 1, . . ., T + m, a similar designation is utilized.

g/ These statistics are descriptive measures of observed (explained and unexplained), model (correct and incorrect), and joint (corresponding and noncorresponding) information.

counters in time series data.[21] When standard estimation procedures are applied, some of these criteria employ approaches which yield Classical tests while others are--at this stage of our knowledge--descriptive and geared to particular model applications.[22]

In comparing alternative model representations on the basis of their explanatory power, the idea is essentially that the model which explains the sample data best is the most valid of those considered. Comparisons of this type are obviously difficult since some model representations may perform well on the basis of one or more criteria but poorly on the basis of other criteria. Thus a weighting scheme of some sort is required if two or more criteria are utilized. In general, the degree of model validity increases with the number of positive results registered when the selected criteria are applied.

These explanatory model 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 for the jointly determined variables with the 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 the 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, and Rausser and Johnson, 1972). Although comparisons simulated with actual series seems to be a natural alternative for evaluating the comparative validity of econometric models, they have as will be indicated, some decided limitations.

Presuming the availability of non-sample data, 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 alternative 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 present 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 criteria are also recorded in Table 1. Each involves an attempt to access the homogenity of predictions for alternative models with non-sample data.

Model comparisons in context of predictive criteria appear to be made best on an *ex post* rather than an *ex ante* basis. This follows since 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 in the model and no impurities are created by the errors in estimating or 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, *et al.*, 1970 and Dhrymes, *et al.*, 1972). In the more general situations, however, no statistical tests appear to be known at this time. This simply reflects the fact that statisticians have not yet succeeded in isolating a proper way of evaluating a sequence of dynamically generated forecasts for a set of jointly determined variables (Rausser and Johnson, 1972).

One point of departure from the Classical situation which frequently occurs in dealing with systems models concerns data availability. Current experience indicates that it is unlikely that available data can support ambitious systems models (Duley, *et al.*, 1971, Fletcher, *et al.*, 1970, Halter, _et al_., 1970, G. L. Johnson, _et al_., 1971, and Thorbecke, 1971). The only alternative in such situations is to supply missing or non-estimable parameter values from prior or subjective knowledge, whether based on experience with similar relationships from corresponding situations or on educated guesses of individuals familiar with such systems. These types of prior information can be incorporated using Classical statistical methods (Judge and Yancey, 1971) or as suggested earlier, in the context of a Bayesian formulation of the problem (Zellner, 1971). However, such information is obtained, it is likely that the estimated portion of the model will be examined together with the pre-specified parameter values before a final version of the model is obtained. In short, the estimation procedure for the structural model is under these circumstances probably best described as a sequential or adaptive type of process.

The adaptive or sequential estimation procedures required in the case of insufficient data leave little to salvage in terms of straightforward applications of the Classical verification methods (Van Horn, 1971). Predictive tests based on sample data have less meaning due to the sequential or adaptive estimation procedures. Tests on estimates of individual parameters are also of very limited value for the same reasons. Finally, it is highly unlikely that data will be reserved for testing the model against non-sample observations. When these problems due to data limitations are considered together with the previously mentioned problem of alternative structural representations, it is clear that the conventional approaches to verification are largely uninformative in the case of complex systems models. It is the inconclusiveness of standard models in such situations that has led researchers using large scale and perhaps nonlinear systems models to examine internal consistency as a means of verification.

Internal Consistency

The motivation for examining internal consistency as a basis for verification can be illustrated rather nicely with the following situation.[23] A model describing a system has been estimated (using the term loosely) and tested where possible using the Classical and descriptive statistical procedures referred to above. If the results of this first type of verification procedure are not particularly convincing, as is often the case, further information as to 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.[24] If these dynamic implications are consistent with the established theory or with pre-suppositions as to the functioning of the system, then such an investigation is said to yield results which support the validity of the model. On the other hand, if the dynamic implications are inconsistent with the theory and institutional knowledge of the system, the validity of the model is contradicted. If the dynamic implications of the model contribute to the evidence of validity, then we say the structural model is internally consistent.

There are well established methods for investigating the dynamic implications of both linear and nonlinear structural models (Fishman and Kiviat, 1967, Howrey and Klein, 1972, Howrey, 1971, Howrey and Kelegian, 1969, and Rausser and Johnson, 1972). In brief, these methods are based upon the fact that lagged relationships entering the systems models can be viewed as difference or differential equations. Aside from straightforward impact multiplier analyses which can be based directly on the reduced forms, other types of multipliers (e.g., interim, cumulated, and equilibrium) based on final forms or solutions of difference equations can be obtained and examinations of stability and convergence can be conducted. For purposes of the general discussion, it suffices to observe that applications of methods for examining internal consistency typically proceed in the context of the estimated reduced form for the system structure. Hence, the procedure is to insert the partially tested estimates of the structural parameters, obtain the reduced form and determine its dynamic properties.

Both analytical and simulation methods can be applied for examining the properties of systems of the type usually encountered (Fishman and Kiviat, 1967, Howrey and Kelegian, 1969, Naylor, 1970, and Rausser and Johnson, 1972). Although there is currently some disagreement as to the circumstances under which one general method is preferred to another, the following guidelines seem to be reasonable (Howrey and Kelegian, 1969 and Naylor, 1970). For nonstochastic and comparatively simple linear and non-linear models analytical methods offer advantages to the simulation approach (Howrey and Kelegian, 1969 and Rausser and Johnson, 1972). However, as the models vecome 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 a more tractable means of obtaining information about the dynamic behavior of the system. While the simulation methods have the possible advantage of being applied to the structural form of the model, the general implications of the simulated series are in many cases unclear. Hence, it seems reasonable to suggest that simulation as a means of obtaining dynamic properties of sectoral models is coming to be regarded as the applicable alternative only when analytical or analytical simulation methods (Rausser and Johnson, 1972) are infeasible. The appropriate method is, therefore, mainly a question of individual judgment regarding the feasibility of using analytical methods.

Normative Considerations

As previously indicated, models of economic systems are typically behavioral in nature. The behavioral expressions incorporated in the structures of such models may be refined in terms of previous empirical and theoretical investigations--as is the case with consumption functions used in macroeconomic systems models--or more descriptive--as might be found in rules of thumb employed in firm or process models. In addition to the fact that models of economic systems are behavioral, it is important to recognize that they are typically complex, involving perhaps many types of such relations.

Now the behavioralist view is that such relationships are descriptive and, therefore, do not require inquiries as to their normative underpinnings. The positive view would assert that it really makes no difference as to whether or not the behavioral specifications contain implicit normative assumptions. If the model containing these behavioral conditions has predictive power, then we employ it or, more properly, we only reject models for lack of predictive power. Neither of these approaches, however, represents a very comfortable position for applied models of economic systems (Johnson and Zerby, 1972). It is well known, for instance, that specifications of individual supply and demand functions involve normative considerations. Moreover, as we depart from the purely competitive system, models tends to include implicit judgments as to the advisability of concentration in industries, land reforms, income redistributions, etc. It is pleasant to think in terms of generating such statements or relations from primitive and widely acceptable normative assumptions. Economic theory has not, however, progressed to the point of providing enough structure so that models of complex economic systems can be set forth and applied on the basis of such primitive assumptions. We are left, therefore, with models including behavioral relationships which involve non-primitive and possibly conflicting normative assumptions.

These sorts of difficulties were, of course, recognized at an early point in the development of applied work based on modelling results (Heady, 1952 and Black 1953). A partial solution is possible if the concept of conditional normativism is used (Johnson and Zerby, 1972). That is, by making certain normative suppositions in constructing the models and then presenting the results or prescriptions developed from utilizing the models on the condition that the potential users subscribe to the underlying normative assumptions. Linear programming analysis as used in applied studies of firms is a frequent reference to examples of this approach. The same approach is obviously applicable to more complex models--complex in terms of their normative assumptions. However, much of the advantage is lost because of the likely reduction in the applicability of the results. It is in connection with the difficulties associated with the problem of selecting the "appropriate" normative criteria that the issue of normative verification is raised. That is, if we wish to construct models which are representative of a specific economic system then it is important to at least attempt to ascertain the appropriate normative assumptions on which to base the models.[25]

V. APPLICATIONS IN AGRICULTURAL ECONOMICS

Some important applications of systems and simulation methods in Agricultural Economics are catalogued and discussed in this section. As systems analysis methods are comparatively new in Agricultural Economics, the applications mentioned are all from the previous two decades. With the exception of gaming (which due to its intensive use as a pedagogical tool is treated specifically), the applications are arrayed and discussed by subject area. The subject areas identified for attention involve systems models for firms and processes, markets, aggregate problems, economic development processes, and natural resource problems. The arrangement of the survey along these admittedly rather arbitrary subject area lines is designed to serve as a basis for comments as to the comparative development of systems methods in the various fields and to provide reasonably homogenous conditions for evaluating the modelling attempts in the designated areas. The latter comments will be rather closely identified with the general observations on systems and systems analysis which have been made previously. As a complete or thorough survey of this work in each of the designated areas is beyond the scope of our current assignment, we confine our comments largely to the strengths and weaknesses of the studies reported. In particular, the results facilitated by the use of systems and simulation concepts will be examined. The overview with respect to contributions of Agricultural Economists in the development and extension of these methods is reserved for section VI.

GAMES AND GAMING

Games and gaming as they relate to concepts of systems and simulation owe their beginnings to the development of similar types of constructs for the purpose of investigating the potential of various strategies in war. This historical perspective for the more modern developments with gaming as applied in Agricultural Economics has been nicely documented by Longsworth (1970). These exercises in war-gaming apparently attracted the attention of business oriented people in about 1956 when the American Management Association sponsored a group to develop a management game based on concepts and methods from the U.S. Air Force inventory management game called Monopologs (Longsworth, 1970 and Bellman, et al., 1957). The efforts of these individuals and the American Management Association sponsored substantial interest in the use of management games as teaching or learning devices during the late 1950's and early 1960's (Greenlaw, et al., 1962). These management games exercises have been described as falling into three rather broadly defined categories--"(a) the total-enterprise games which include the early top management games as well as their much more complex descendants; (b) the specialized or industry games which relate to a specific industry; and (c) the functional games" Longsworth (1970, p. 4).

Early interests of Agricultural Economists in connection with these developments in games is typically identified with the names of Babb, Eisgruber and Hutton, (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. An equally early application, but with a slightly different orientation, involves production control in a cheese plant (Glickstein, 1961). Although subsequent efforts have presented somewhat more complex problems as well as diverse enterprises (see tabular survey Table II) it is apparent from the listing of games and their characteristics that the larger impact of gaming models has been in farm management. A very extensive survey of these efforts is contained in Longsworth (1969).

Systems, Games and Simulation

Although somewhat different in orientation than the other topics examined in this survey, it will be clear that models concerned with games and gaming fit within the conceptual framework provided in the first part of the paper. To begin, we note that games as viewed from the standpoint of participants are decision problems. That is, the participants are typically provided with some--perhaps not complete--information about the game and asked to play the game by making decisions according to some artificially specified criterion or whatever implicit criteria they might select. In terms of our previous

TABLE II

A Tabular Survey of Gaming Models in Agricultural Economics

References	Situation	Objective	Time unit[a/]	Multi-stage	Competitive[b/]	Open-closed[c/]	Decision variables	Computerized	Stochastic
Babb and Eisgruber, [1966]	Each team manages a farm supply store that has been deteriorating financially	To learn about management in a competitive environment	O	x		O	Prices, inventory, credit, hiring, firing, storage capacity, truck expenditures, investments	x	x
Babb and Eisgruber, [1966]	As many as four dairies compete in a local market	To stress importance of financial planning and to understand the nature of competition and strategy formulation	M	x		O	Prices, advertising, hiring, firing, commission rates	x	
Babb and Eisgruber, [1966]	Operating a farm in pure competition	To stress farm management and illustrate choice of combination of products	Y	x	x	O	Production levels, method of production, land purchase, sale and/or purchase of breeding stock	x	x
[illegible]nd Ei[illegible]uber, [1966]	Firms selling four types of products in an urban market	To learn about marketing management	O	x	x	O	Margins, specials, advertising, orders, stamps, personnel, loans	x	
Bellman, [1957]	Firms competing for a known consumer market	To provide a means of executive training using simulation techniques in a multi-person business game, stress on long-run policy decisions	O	x	x	O	Price, production rate, marketing budget, R&D budget, investment	x	
Bente and Williams, [1965]	Teams operate four egg handling plants in Illinois	To stress relationship between a firm and its environment	M	x		C	Input purchases, capital investments, prices paid	x	x
Curtis, [1968]	Single farm management	To evaluate the effectiveness of business simulation model for teaching farm business analysis and record keeping for high school and adult students; the simulation technique is compared with more traditional methods	Y	x		C	Basic inputs, debt servicing, borrowing	x	
Eisgruber, [1965]	Operating a single farm	To examine the effects of limited capital, uncertainty, price cycles, specialization vs. diversification, etc. at discretion of management	Y	x	x	C	Crop levels, fertilizer (amounts, and types), livestock, land, breeding stock purchased or sold	x	x

TABLE II (Con't.)

A Tabular Survey of Gaming Models in Agricultural Economics

References	Situation	Objective	Time unit[a/]	Multi-stage	Competitive[b/]	Open-closed[c/]	Decision variables	Computerized	Stochastic
Farris, et al., [1966]	Operation of a San Joaquin Valley (Ca.) farm	To stress farm operating decisions	Y	x	x	C	Production levels, land purchases, machinery combinations	x	x
Frazier, et al., [1970]	Livestock auction market	To determine the inherent inefficiencies of a given size and scale of auction markets and evaluate systems simulations as a research and/or management tool	O	x	x	C	Utilization of facilities, storage capacity, utilization of storage, length of entry and exit queues; volume of livestock	x	x
Frahm and Schrader, [1970]	English (Ascending bid) and Dutch (decending) auction markets compared with respect to (i) price variation (ii) speed of convergence (iii) average prices and (iv) observed equilibrium prices	To test hypotheses under given situation	O	x	x	O	Assigned selling price and marginal processing cost		
Fuller [no date]	Connecticut Valley cash crop and dairy farm	To relate managerial principles to decision-making	Y	x	x	O	Production levels of crops and dairy	x	x
Fuller [no date]	New England brown egg poultry farm	To stress impact of trade-off strategies between income and security	Y	x	x	C	Selection of marketing system, capital investments, production levels	x	x
Greenlaw, et al., [1962]	Firm selling single (unnamed) product in two regional markets; demand fluctuations present	To provide a dynamic experience in marketing decision-making. To emphasize competitive interaction in marketing decision making and difficulties of internal organization	O	x	x	O	Price, expenditure for sales force, national and local advertising, of less importance are production and transportation		
Greenlaw, et al., [1962]	Physical production and distribution of goods; producer-wholesaler-retailer links are emphasized	To examine order and inventory policies in a dynamic marketing situation	O	x		O	Price, orders, inventory		
Hutton and Hinman, [1968]	User specifies situation and parameters that pertain to his concerns	To evaluate alternative farm plans	Y		x	O	Inputs, level of capital, financing, sales, technical coefficients, production levels	x	x
Longsworth, [1970]	Australian dry-land grazing and cropping farm	To weigh short-run tactical decisions vs. long-run strategy	Y	x	x	O	When to buy and sell, levels of output, capital investments	x	x

TABLE II (Con't.)

A Tabular Survey of Gaming Models in Agricultural Economics

References	Situation	Objective	Time unit[a/]	Multi-stage	Competitive[b/]	Open-closed[c/]	Decision variables	Computerized	Stochastic
McKenny, [1962]	Firms selling three (similar) products	To provide production planning experience and demonstrate interdependency of functional decisions within a firm. Stress is on time dimension	O	x	x	O	Price, advertising expenditure, design and styling expense, production levels, investment in plant capacity and/or securities	x	
Smith, [1964]	1) Sellers make offers, buyers may accept or reject 2) Sellers and buyers both active in the market process 3) buyers make bids, sellers may accept or reject	To test hypotheses concerning the price equilibrium and adjustment behavior of markets under three market organization conditions	O	x	x	O	Trading session prices along with price limits		
[illegible]h and [illegible]s, [no date]	Managing a 640-acre farm	To relate economic principles and farm management	M	x	x	C	Levels of production, land and machinery purchases	x	
Vincent, [1970]	Farm construction and operation	To familiarize participants with problems faced in farm development	Y	x	x	O	Production levels, land purchases, capital allocation	x	x
Walker and Halbrook, [no date]	A 200-acre corn farm in the great plains area	To understand problems of growth under uncertainty	O	x	x	C	Livestock inventory and capital investment	-	x
Wehrly, [no date]	Managing a farm on the southern high plains of Texas	To demonstrate how plans made under perfect knowledge work out under "average" conditions	Y	x	x	C	Crop production levels		x
W[illegible] and [illegible]rdson, [[illegible]9]	Statistical model of auction market with application to Australian wool	To develop simulation model of an auction market demonstrating the relationship between variation in valuation, price variation and the number of independent bidders in the market	O	x	x	O	Product quality, price limits, number of bidders, size of lots	x	x

a/ "M" stands for monthly decision-making and "Y" for yearly. "O" indicates time dimension was unspecified, or other than monthly or yearly

b/ A competitive game is one in which the actions of one team do not effect the outcome of another team

c/ "O" indicates open, "C" indicates closed discussion (section III) the individual or participant is implicitly required to formulate a system model of the decision type.

The game itself is likewise a model of a system. As may be observed from the table containing the tabular survey, the games are typically models of agricultural producing or farming units. In terms of the classificatory system we have developed, these games or systems models are of the descriptive - behavioral or decision type. The situation is then one in which a model of a system is constructed and the participant is required to form some representation of the model (for the system) as a basis for developing a strategy for playing. If games are utilized as a pedagogical device, then it is taken as an article of faith that the process of playing the game will result in increased proficiency. This increase in proficiency may, of course, come about as a consequence of an increase in the participants modelling 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 the individual(s) play are utilized as a basis for determining behavioral characteristics of the participants or the game itself if the players interact with the game. In the first case the research objective involves an investigation of the means by which various types of economic agents make decisions. The second case involves the types of studies typically identified with the subject of experimental economics (Smith, 1964, Whan and Richardson, 1969, Frahm and Schrader, 1970, Frazier, et al., 1970).

Given this view of the gaming models, it should be apparent that the systems framework we have developed and the questions raised in regard to the formulation of systems models encompasses the type of models employed in gaming. With respect to the systems framework it is clear from survey

Table I that most of the games reported are dynamic and stochastic. While the major portion of the games involve a process in which the participant is playing against the system as contained in the abstract game model, there are games in which the individual participants are themselves a part of the structure and their performance in the game is dependent upon others actions. This latter type of game is, of course, more easily identified with the war games mentioned in the brief historical remarks. Both of these types of games as they have been applied in Agricultural Economics can be thought of as open simulations (Orcutt, et al., 1961). That is, the actions of the player vis-a-vis the game are not entirely prescribed by the conditions of the operation. If the game is closed, then the process by which the player arrives at his actions--his "optimal" strategy--is in principle, determined by the rules of the game. Simulations or play under these latter conditions should, when the game is complex, provide for an experimental procedure which will let the player determine an approximately optimal strategy. The simpler of these types of games provide the link between games and gaming in a systems and simulation context and the more formal literature on the theory of games (Von Neumann and Morgenstern, 1950, Shubik, 1960 and Wagner, 1958).

Problems of systems model formulation as they relate to games appear as yet to have received little formal attention. Although it is clear from many of the operative games that considerable efforts have been made to construct realistic games, i.e., make the system model a valid model of the system being modelled, little formal information is available which might be utilized to determine this realism on a more scientific basis. Efforts in this direction would, as our preliminary discussion suggested, involve more systematic procedures for structure specification and parameter estimation.

Furthermore, regarding the simulation of the gaming models or play, it is apparent from the previous discussion that games and gaming exercises could become more useful as a learning tool if more attention were given to the process by which participants arrive at strategies. To this point, the various games appear to do little more than force participants to formulate their objectives for play. The exercises as they relate to developing problem solving abilities would be enhanced if more careful consideration were given to the process by which the simulations are designed to result in optimal strategies.[26]

As a final comment, it seems appropriate to mention that Agricultural Economists appear to have devoted little attention to problems of determining the educational value of games. With the exception of the work by Curtis (1968), Babb (1964), Babb and Eisgruber (1966), and McKenny (1962), (all of which in some respects are rather surprising in terms of findings as to the educational value of games,[27] little formal work is available on this subject. It would seem that if games are to be used as teaching devices then somewhat more careful evaluations of the effectiveness of the various available games in different teaching and extension contexts would be useful in the design of new games and in promoting more informed use of those which currently exist.

FIRM AND PROCESS MODELS

Systems models of firms and processes have, as would be anticipated, a very strong decision orientation. That is, they are typically concerned with the problem of providing information which can be utilized by actual decision units for improved resource allocation. More specifically, the majority of the systems models are concerned with firm decision problems and are designed to produce results which can be helpful in dealing with uncertainty, growth and adjustment, or adaptation problems. Each of these problem areas raises substantial conceptual and computational difficulties in the context of the more traditional neoclassical and activity analysis models of the firm. The flexibility of the systems approach has, therefore, given rise to a rather large number of comparatively ambitious modelling efforts in this area.

As tabular survey Table III shows, these models are mostly stochastic, dynamic and involve some nonlinearities.[28] Consequently, direct solution methods--even for the more simple of the objective or criterion functions employed--are usually infeasible. The models are, therefore, simulated on the basis of particular types of policies in order to determine their sensitivity to various structural changes, alternative settings of the control variables and the like. Results of the simulations or experiments are then evaluated in terms of the objective function or simply presented as outcomes to be anticipated from the examined courses of action.

Although not mutually exclusive, the studies listed in survey Table III can be classified according to whether they are process, management and farm planning or growth models. The process models involve specific types of producing and marketing activities or plants over which a firm has control. These studies are typified by results along the lines of those obtained by Brooks (1962), Cloud, et al., (1968), Dorster (1970), Glickstein (1962), Smith and Parks (1967), Sorensen and Gilheany (1970) and Wright and Dent (1969). Of these models, the work by Glickstein, et al., is noteworthy since it preceded many of those which followed. It provides a general acquaintance with the systems approach in processing types of problems and seems to have had some influence on a number of the subsequent studies. The recent models are generally more elaborate in terms of complexity and sources of uncertainty. As with most process models, the studies have comparatively (when specified)

Tabular Survey of Firm and Process Simulation
Models in Agricultural Economics

References	Objectives	Components	Decision variables	Model characteristics: Dynamic	Stochastic	Non-linear	Verification	Model application1/	Experimental design2/	Computer language3/
Anderson, [1968]	To establish optimum crop patterns on irrigated farms based on preseason water supply estimates	Moisture conditions, water supply	Water allocation, acreage restrictions			x		DM	AD	FL
Armstrong, et al., [1970]	To combine simulation and linear programming to study farm firm growth	Farm simulator for short term tactical decisions, an ex post linear programming routine	Choice of enterprise, production methods, production levels	x				DM	AD	FL
Brooks, [1962]	To model the C&H sugar refinery at Crockett	Input, output, processing stations, demand, capacity	Production levels, input levels	x				DM	BD	FL
Cloud, et al., [1968]	To determine the optimal date for hay harvesting	Output, machinery, and weather	Scheduling of activities, selection of production mode, inputs			x		DM	CD	FL
Donaldson and Webster, [1968]	Utilize simulation to assist in selecting farm plans with highest gross margins	Production, resource, revenue	Production preferences input levels		x			DM	BD	FL
Doster, [1970]	To use a simulator to help in formulating plans for a corn farm	Harvesting, hauling, handling, haying, storage, marketing	Planting schedule, form and time of sale, harvest schedules, equipment utilization					DM	BD	FL
Eidman, et al., [1967]	To demonstrate Bayesian decision theory to management decisions under uncertainty using commerical turkey production as an example	Capital stock, production, mortality, net returns	Marketing strategy: contract or independent	x	x	x		DM	DD	FL
Gli[illegible]in, et a[illegible]., [1962]	To apply simulation to a cheese manufacturing plant to analyze production under varying conditions	Plant and equipment, supplies and services, and labor	Purchasing policy, process scheduling	x	x	x		DM	BD	FL
Halter and Dean, [1965]	To use simulation in evaluating management policies under uncertainty using a large scale ranch as an example	Rangeland, feedlot, and weather environment	Purchasing, scheduling, and selling	x	x	x		DM	BD	DL
Harle, [1968]	To use simulation in farm planning by concentrating on data production rather than data manipulation	Capital, production, and risk	Method of production, and production levels	x	x	x		DM	BD	N.A.
Hinman and Hutton, [1970]	To incorporate a generally accepted theory of the firm into a firm simulator to handle many different farm situations	Production, resources, inventory, input, and financial	Debt level, marketing strategy, investment, input levels, and insurance	x	x			DM	BD	FL

TABLE III (Con't.)

Tabular Survey of Firm and Process Simulation Models in Agricultural Economics

References	Objectives	Components	Decision variables	Model characteristics: dynamic	Model characteristics: Stochastic	Model characteristics: Non-linear	Verification	Model application1/	Experimental design2/	Computer language3/
Hutton, [1966]	To use a simulation model of a dairy herd in the selection of a herd replacement policy	Inputs, outputs, capital, and financial	Replacement and input levels	x	x	x		DM	BD	FL
Patrick and Eisgruber, [1968]	To measure the influence of managerial ability and capital market structure on the rate of farm firm growth	Managerial, resource, financial, and expectations	Credit availability and terms, investment	x		x		EM	DD	FL
Smith and Parks, [1967]	To predict, on a probability basis, optimum levels of fertilizer application when drought is considered to be a random variable	Input, output, and environment	Level of fertilizer to apply		x	x		DM	AD	FL
Sorensen and Gilheany, [1970]	To evaluate different harvesting strategies on a sugar plantation	Harvest, cane hauling, milling, and weather	Labor allocation and level, harvest scheduling, machinery assignment	x	x	x		DM	BD	GL
Vincent, [1970 a]	To construct a model to explain the future state of the poultry producers	Feed production, egg production, financial, and capital	Investment levels, production levels, and marketing strategy	x	x	x		DM	ED	FL
Vincent, [1970 b]	To explain the use of a farm simulator that can be adapted to many different farm firms	Capital and credit, livestock and crops, machinery	Farm acquisition, type and quantity of capital stock and production levels	x	x	x		DM	BD	FL
Wright and Dent [1969]	To measure the effect of withdrawing land from grazing to cropping for part of the year	Biological environment, market structure, input and output	Land allocation	x		x		DM	DD	FL
Zusman and ~~Amaig~~ Amiad, [1965]	To determine optimal farm plans under weather uncertainty	Weather, market, livestock, inventory, crop, and seasonal	Production levels, livestock herd size, inventory levels, sales, and purchases	x	x	x		DM	FD	FL

TABLE III (Con't.)

Tabular Survey of Firm and Process Simulation Models in Agricultural Economics

1/ DM denotes a decision model application, BM denotes a behavioral model application and FM denotes a forecasting model application.

2/ AD denotes historical simulations with given levels of exogenous factors.

BD denotes an examination of alternative levels of exogenous factors with no distinct order or pattern.

CD denotes the use of various multi-stage techniques to eliminate inferior alternatives from further scrutiny in the optimization search.

DD denotes an examination of all presented alternatives (full factorial design).

ED denotes an examination of selected alternatives with some sort of pattern (partial or fractional factorial designs).

FD denotes an examination of selected alternatives with some sort of pattern (fractional factorial designs) combined with formal search procedures.

GD denotes a central composite (rotatable) design.

3/ FL denotes FORTRAN.

DL denotes DYNAMO.

GL denotes general purpose systems simulation (GPSS).

AL denotes ALGOL.

PL denotes program SIMULATE.

OL denotes FORDYN.

simple objectives--minimizing costs, maximizing returns over costs, and mean-variance types of criteria (E. V. efficiency criteria).

The second group of models may be thought of as fulfilling the need for budgeting types of requirements in farm planning. These models are the more numerous of those listed--perhaps because of the rather general concern with farm planning in traditional Agricultural Economics Departments. Studies of this type include those by Anderson (1968), Donaldson and Webster (1968), Eidman, et al., (1967), Halter and Dean (1965), Hinman and Hutton (1970), Hutton (1966), Vincent (1970 a), Vincent (1970), and Zusman and Amiad (1965). The advantage of the systems approach to the traditional planning problem is again its flexibility. Numerous production activities can be considered along with many types of strategies for combining them. It is also easier to plan over time utilizing the systems approach since, again, numerous activities and strategies can be rather inexpensively examined.

Although more will be said about these studies, there are three of the planning type models which merit some special comment. These studies represent innovations of methods which appear to be promising for future planning work. The first, by Eidman, et al., (1967) is of importance due to the type of decision mechanism employed in dealing with the uncertainty in the planning process. Objective functions of the type implicit in the Bayesian formulation of decision problems and the related ones facilitated by the expected utility hypothesis (Von Neumann and Morgenstern, 1950) allow the possibility for dealing more systematically with decision models in farm planning. The second study by Halter and Dean (1965) is of consequence because it involved the use of a special computer language. Although, (as our previous discussion would indicate), the need for these special purpose languages is somewhat lessened due to the options which are being incorporated into the more standard language, the study is important since it represents a first application of a specialized simulation language. The third study, by Zusman and Amiad (1965) is noteworthy because of the methods applied in examining the response surface of the firm model and for the way in which the model was simulated. With respect to the former, the methods suggested and discussed by these authors preceded by a reasonable margin, the interests of the systems modellers in problems of experimental design and response surface identification (Naylor, et al., 1969). As we attempted to indicate in section III, these problems and the proper treatment of them are of substantial importance in simulation modelling. The method of simulation in connection with the decision problem is what we have earlier termed analytical simulation (Dorfman, 1965). The study, therefore, contains a discussion and application of two techiques which substantially preceded general interest in the related problems by those concerned with the development of systems analysis methods.

Returning to the third group of studies--those on firm growth--we find a limited number of references in the tabular survey. Specifically, those by Armstrong, et al., (1970), Harle (1968), Patrick and Eisgruber (1968) are the growth studies listed. With respect to firm growth, the construction of the tabular survey was a particular problem. In fact, as a result of the difficult investment and decision problems involved in the study of firm growth, most of the applied studies in the area could be classified as being based on systems and simulation concepts. The study of firm growth in Agricultural Economics represents an interesting occurrence in applied work. For when the growth work began--most likely due to observed problems in increasing farm size (however measured)--it was largely outside of the precepts of orthodox economic theory.[29] The systems approach (although not called that by name), again due to its flexibility, was of considerable value in faciliting the applied work in this area.

In reviewing all of studies appearing in Table III as they relate to the general framework for systems analysis and simulation presented in the previous sections, we find them to be deficient in a number of respects. As noted in this Table, the work on verification has been limited. Although the quality of the results obtained from some of the modelling efforts would suggest that a substantial amount of informal work was done on verification, there is little mention of the application of more formal and systematic tests of the type mentioned in section IV. As these models have as their main function the generation of information to be employed by operators in the system being modelled, it would appear that more explicit and systematic attempts to verify the models would be advantageous.

A second area in which there appears to be a possibility for improving the models and results involves 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. The models are sufficiently complex (principally in terms of nonlinearities and stochastic components) that the the study of response surfaces without considerable attention to experimental design may provide misleading information. As these models become increasingly more realistic, and consequently more complex, the problem of identifying the response surfaces with a high degree of reliability is likely to be more important.

Our last observation concerns the criterion functions implicitly or explicitly employed in these models. Clearly, since the models are stochastic in nature it is necessary to employ various kinds of indexing schemes which can accommodate the stochastic arguments. As mentioned earlier, the Bayesian and relatedly expected utility approaches seem to represent an encouraging development in this regard. The earlier noted work of Eidman, et al., (1967) represents a positive step in this direction. As these types of ideas begin to be introduced, however, it will be necessary to attempt to take advantage of their full benefits in terms of possibilities for analytical solutions (Burt, 1968). They also suggest that the analytical simulation methods which were applied in the work of Zusman and Amiad (1965) will become more commonplace in future work with process and firm models.

MARKET OR INDUSTRY MODELS

This classification encompasses a number of market or industry system investigations. The models constructed for these investigations typically involve elements surrounding the movement of one or more commodities from producers to consumers. Many of the studies are explicitly concerned with distribution channel systems while others are concerned with single market systems for particular products. The problems confronted are associated with improving our understanding of the behavior of such systems and their likely movements over some future application period, or with attempts to improve the decision processes of the elements comprising the system under examination. As indicated in Table IV, most of the applications are behavioral in origin and, thus, are associated with improving existing knowledge about the nature of markets, distribution channel linkages, and industry component interactions.

The major components of these market or industry models are usually affiliated with one or more of the following: consumer, retailer, wholesaler, transportation, producer, inventory, and foreign trade. These components are often represented in a decomposable fashion and the interactions among them are treated recursively. The model representations of these components are frequently characterized by lagged effects, interacting variables, as well as nonlinear relationships. In some cases the number of dynamic, nonlinear relationships are few while in other cases they are numerous. For all cases, however, the departures from (intrinsic) linearity are not substantial. Although most of the constructed models contain stochastic elements, only five of the twenty studies reported in Table IV recognize stochastic components when simulation experiments are performed. That is, the vast majority of the models are only investigated in their deterministic or expected value form.

The experimental designs utilized to conduct simulation experiments for these models vary from central composite designs (GD) to naive designs (BD). Of the sixteen studies reported in Table IV for which experimental designs were employed, eleven utilized naive designs, one utilized factorial designs, three utilized partial factorial designs, and one utilized a central composite design. In the case of verification procedures, only two studies (Naylor, et al., [1967 b] and Weymar [1968]) proceed beyond simple graphical comparisons of sample and explained or generated values of selected endogenous variables. Few formal tests or even descriptive measures are provided to examine the validity of the constructed models.

The specific applications selected for further examination include Cohen [1960], Balderston and Hoggatt [1962], Raulerson and Langham [1970], Crom and Maki [1965], Naylor, et al., [1967 b], Vernon, et al., [1969], and Candler and Cartwright [1969]. Although the Cohen [1960] and Balderston and Hoggatt [1962] studies are not directly related to agricultural economic problems, they are surveyed here because of their importance and the foundation they formed for much of subsequent work which appears in Table IV. Both of these studies are concerned with distribution channel simulations. The model developed by Cohen, consisting of over sixty equations, is an attempt to explain the behavior of various elements in the vertical structure of the shoe

TABLE IV (Con't.)

Tabular Survey of Market or Industry Simulation Models in Agricultural Economics

eferences	Objectives	Components	Decision variables	Model characteristics: Dynamic	Stochastic	Non-linear	Verification	Model application1/	Experimental design2/	Computer language3/
rom and aki, [1965]	To develop a means of studying historical and projected changes in the livestock-meat economy's market organization and structure	Pork, beef, inventory, production, foreign trade, demand, margins	Slaughter production levels, inventory levels, breeding, culling	x		x		BM	AD	FL
esai, [1968]	To evaluate the operation of the milk stabilization program in California and to indicate the direction and magnitude of possible changes	Producers, processors, market share, demand, cost	Production prices, advertising, government price regulation	x	x	x		BM	ED	FL
uewer and aki, [1966]	To investigate the interrelationships and interactions among the various parts of the livestock-meat industry from a systems analysis standpoint	Producers, markets, slaughters, processors, wholesalers, retailers, households	Purchases, sales, production levels, entry, exit, transaction partner selection	x				BM	BD	FL
rench and atsumato, 1969]	To develop economic information which may aid various groups of the brussels sprouts industry in their decision-making	Production, freezer, fresh, inventory	Marketing policy, sprout size, product allocations, inventory levels	x		x		FM	BD	FL
oenig, et al., 1971]	To demonstrate how systems theory can be employed in the analysis and control of semi-closed biological processes of the type encountered in the agricultural industry	Feed, labor, plants (broiler, pullet, egg), markets	Sales, feed and labor inputs, government purchases	x				DM	BD	FL
rebs, et al., 1972]	To evaluate and compare various support and supply control policies for navy beans in the U.S. by means of simulation	Domestic supply and demand, foreign supply and demand	Government prices, support levels, marketing control, acreage control, supply allocation	x		x		DM	BD	FL
anetsch, 1964]	To describe work in progress on the development of a computer simulation model for the softwood plywood industry	Integrated producers, independent producers, integrated jobbers and office wholesalers, independent jobbers, independent office wholesalers, less than carload retailers, carload retailers, less than carload markets, carload market	Production levels, sales, inventory prices, levels	x				BM	BD	FL
ylor, et al., 967b]	To simulate the textile industry and to present three alternative validation tests	Supply, demand, employment, profit	Advertising, inventory levels, investment purchases	x	x	x	x	BM	AD	FL

Tabular Survey of Market or Industry Simulation
Models in Agricultural Economics

References	Objectives	Components	Decision variables	Model characteristics: Dynamic	Model characteristics: Stochastic	Model characteristics: Nonlinear	Verification	Model application1/	Experimental design2/	Computer language3/
Armbruster, et al., [1972]	To evaluate farm marketing boards as a means of increasing farm bargaining power: test case Western late potato system	Production, marketing, bargaining	Negotiated price; production quotas, acreage, marketing allocation	x	x	x		DM	ED	FL
Balderston and Hoggatt, [1962]	To examine the dynamics of a market viewed as a complex system of behavior in which information is limited and costly	Timber growers, retailers, broker transactions	Price, output, financing	x	x	x	N.A.	BM	ED	FL
Barnum, [1971]	To measure the effect of the introduction of stochastic terms on the reliability of deterministic conclusions obtained from simulation of the food grains market in India	Prices, production, income, imports	Government purchases, importation of P.L. 480 surplus foodgrains	x	x			DM	DD	FL
Bender, [1966]	To provide a basis for determining what season of the year promotional activities should be concentrated and the effects of changes in feed grain prices on the broiler industry	Costs, capacity, seasonal demand	Production levels, input levels, investment, purchases			x		BM	BD	FL
Benson, [1969]	To develop a computer simulation model for interregional competition in the broiler industry that can answer questions at the firm, region and industry level	Firm, capacity, supply, demand, region	Production levels, feed costs, production scheduling, transportation costs			x		BM	BD	FL
Candler and Cartwright, [1969]	To illustrate the use of experimental design and regression analysis in the estimation of functional relationships as a basis for deriving "performance statistics"	Financial, output prices, input prices	Choice of weights entering the performance function			x		DM	GD	FL
Cohen, [1960]	To examine detailed aspects of business behavior and dynamic interaction among firms using the shoe, leather, hide sequence as an example	Consumer, retailer, manufacture, tanners, hide dealers	Prices, production levels, orders, inventory levels, consumer expenditures	x		x		BM	AD	FL
Crom, [1967]	To indicate the trading pattern changes and the potential for readjustment between alternative market organizations in 1975 under alternative assumptions	Transportation, capacity, labor beef, pork, regional	Regional production, regional consumption, regional allocation					FM	BD	FL

TABLE IV (Con't.)

Tabular Survey of Market or Industry Simulation Models in Agricultural Economics

References	Objectives	Components	Decision variables	Model Characteristics: Dynamic	Sto-chastic	Non-linear	Veri-fica-tion	Model applica-tion1/	Experimental design2/	Computer langu-age3/
Raulerson and Langham, [1968]	To investigate the problem of fluctuating orange supplies and grower profits in the frozen concentrated orange juice sector of the Florida citrus industry	Grower, processor, retailers, consumer	Tree planting, tree removal, supply control, market allocations	x		x		DM	BD	DL
Schruben, [1968]	To indicate the potential usefulness of the systems approach to research in marketing efficiency and to provide guidelines to the systems concept	Transportation, merchandising, cost	Purchase, sales, spatial allocation, product quality					EM	BD	FL
Vernon, *et al.*, [1[illegible]	To explain the behavior of the tobacco industry and evaluate the impact of the efforts of alternative governmental and managerial policies	Leaf production, price, cigarettes	Production levels, pricing, purchases, inventory levels	x		x		EM	AD	FL
Weymar, [1968]	To describe and explain the nature of the dynamic response of the world cocoa industry to annual fluctuations in world cocoa production	World consumptions, price, expectations, inventory	Inventory levels, consumer purchases, price and inventory expectations	x	x	x	x	EM	ED	FL
Zymelman, [1965]	To develop an analog computer solution for the stabilization of employment, prices and profits in the cotton textile gray goods industry	Demand, production, price, inventory	Production levels, inventory levels, orders	x		x		DM	BD	AL

See Table III for footnotes 1, 2, and 3.

leather industry. Balderston and Hoggatt are principally concerned with the mechanisms of price and sales determination in the context of the West Coast lumber industry.

Examining the Cohen model in somewhat greater detail we find that the major decisions modelled consist of price, order level, and production levels for each of the components (hide dealers, leather tanners, shoe manufacturers, shoe retailers, final buyers) represented. Since the system of equations resulting was too complex to solve directly (a number of nonlinear dynamic relationships provided the basis for generating many of the key variables in the system), Cohen resorted to simulating the model over time. In this context, two alternative types of simulation were investigated. One was referred to as one-period and the other as process simulation. The one-period designation utilizes actual historical data to generate the simulated values for each following period while the process approach utilizes the generated endogenous values of past periods to determine the current period's simulated values. The latter approach obviously risks compounding earlier errors and must be employed in forecasting applications (*ex ante*) for which no historical data are available.

In comparing graphically various simulated with actual historical series, Cohen found a number of serious deficiencies in his constructed model.[30] He attributes these deficiencies to the "typical firm" theoretical approach to aggregate econometric model construction. More specifically, he explains his questionable results in terms of the aggregate sector variables not satisfying the same functional forms as the individual firm's behavioral mechanisms. Although his results are not particularly favorable, his model, nevertheless, remains a prototype of sorts for econometric simulation modelling in the area of vertical market structures. The econometric model he constructed as a basis for the two types of simulations mentioned above is, of course, faced with the usual problems, viz., selecting appropriate functional form and variables, obtaining unbiased or at least consistent estimates of the unknown parameters entering the selected equational representations, and validating the complete model.

The Balderston and Hoggatt simulation is less concerned with the entire vertical structure of the lumber industry than with the critical role played by lumber brokers in searching and attempting to match potential sellers (timber growers) and potential buyers (lumber retailers). Their constructed model presumes information is limited and costly. In this context they concentrate on the information and decision behavior of the lumber broker and did not utilize real world data. A number of decision and information rules are specified to govern participants' (timber growers, brokers, retailers) behavior. At the beginning of each market period, growers reveal bid price and quantities, and the prices are not negotiable. The first cycle of a market period begins with each broker sending a "search message" to preferred buyers and sellers. Broker, retailer and grower preferences are determined on the basis of either previous experience (with individual buyers and sellers) or by random selection. From this initial search, if a transaction is not completed, the broker waits for another opportunity to search at the beginning of the next cycle. In the second and subsequent cycles brokers move to their next preferred buyers and sellers repeating their communication and transaction process. The last cycle occurs when all brokers desire no further search for another possible transaction. At this point the market period terminates and all payments are settled between the market participants and the retailers sell their products in the final market.

The major experimental parameters in the Balderston and Hoggatt [1962] simulation are preference orderings (random and on the basis of previous experience) and unit message costs ($10, $12, $48, $192). For different combinations of these two experimental parameters, the authors examine the viability and efficiency of the market. Viability merely suggests that a workable set of behavioral rules has been isolated and was found to exist for each of the eight runs of the model. Market efficiency[31] was found to fall gradually until unit message costs reached the highest level, viz., $198. The simulation results for various levels of the experimental parameters indicated that market pressures and successes of firms with identical endowments might well result in skewed size distributions. Moreover, these distributions were found to depend on preference orderings and message costs.[32] It also found that increased market segmentation[33] was associated with greater trading loyalties and increased message costs.

The Balderston and Hoggatt offers an interesting contrast to the work of Cohen. They begin with a set of postulates regarding the economic behavior of different market participants (rather than with a set of historical input and output data) 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 and, thus, their simulations are essentially synthetic in nature. The principal features of their model include limited information, varying information costs, preference orderings, and localized search.

The Raulerson and Langham [1970] study is also concerned in part with distribution channels. For the Florida frozen concentrated orange juice (FCOJ) industry these authors apply Forrester's [1961] industrial dynamics approach along with the associated DYNAMO simulation language. The model consists of 137 equations representing some features of growers, processors, retailers, and consumers which deal with FCOJ. The parameters entering many of these equations are specified on an a priori or subjective basis. More importantly, many of the equations are specified in an attempt to isolate the information-feedback characteristics and related amplifications and delays which are presumed to exist in the industrial system being modelled. An attempt is made to validate the constructed model by graphically comparing simulated and actual sample values for a few selected variables. Although the ability of the model to tract turning points is emphasized, no measures of model performance in this regard are reported.

As noted in Table IV, the Raulerson and Langham model was constructed to examine alternative policies, i.e., for decision purposes. This examination takes place in the context of policy simulation and an implicit criterion function. The experimental designs utilized for this purpose were naive (BD) involving only two combinations of the four basic policies investigated. Performance variables were associated only with grower profits. More specifically, policies are evaluated only in terms of their ability to stabilize grower profits and supplies at specified levels. The policies investigated were straightforward and may be characterized as: (i) "free market," (ii) product allocation to two separate markets, (iii) removal of productive trees, (iv) curtailment of new tree plantings, (v) combination of (ii) and (iv), and (vi) combination of (ii) and (iv). Once costs of administrating the various policies are introduced and compared to expected benefits, policy (iv) is preferred due to the nature of its control over supplies.[34]

In terms of models discussed above, the Crom and Maki [1965] model is perhaps most closely related to Cohen [1970]. Their purpose is to construct an econometric model which will explain behavior in the beef and pork sectors of the U.S. economy. The model is basically recursive except for beef and pork prices which are jointly determined. The unknown parameters of the model's equations are generally estimated by ordinary least squares and the model is simulated over the historical (sample) record. The simulations are nonstochastic and the experiment design is naive. More importantly, the authors' approach to validation is preposterous. Their approach is to revise their equational specification after examining historical comparisons of actual sample and simulated values. The nature of the revisions are particularly bothersome. They involve changes in the length of time lags, coefficients adjustments, and limiting values. Many of these changes are conditioned upon particular values of the endogenous variables and are determined by graphical comparisons of actual and simulated values. That is, the behavioral relations are modified until a model is obtained which will reproduce the historical (sample) period with sufficient accuracy. Unfortunately, the conditional changes are 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 any acceptable degree the systematic and enduring characteristics of the system under examination.

The Naylor *et al.*, [1967 b] and Vernon, *et al.*, [1969] models are similar in nature to the Cohen [1960] and Crom and Maki [1965] models. Both of these models are constructed around the distributional components of a single industry. Historical time series data are utilized to estimate by ordinary least squares the unknown parameters entering each of these (step-wise) recursive econometric models. The Vernon, et al., [1969] model 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 19 equations, seven are behavioral and twelve are identities. A number of policy variables (e.g., acreage allotments, support prices, sail bank, etc.) are incorporated as exogenous factors to the model but no policy or decision examinations are provided. Many marketing factors such as the effect of advertising expenditures on cigarette consumption are excluded from the analysis. An attempt is made to validate the model by Cohen's [1970] process simulation approach and graphical comparisons of the resulting simulated and actual sample values. Since the model is recursive, departures from linearity are not substantial, and stochastic elements are suppressed, the simulation runs are performed without the need for experimental design methods.

The Naylor, et al., [1967 b] model of the textile industry consists of nine behavioral equations. The basic orientation of model as with the Vernon, et al., model is behavorial. Process simulation analysis is employed over the historical record, no policy alternatives are examined, and experimental design methods are not utilized. One of the principal messages of this study is concerned with the application of alternative verification techniques. In the context of the constructed textile model three techniques, (graphical, spectral, and total variance analysis) are utilized to compare simulation results with observed data. The spectral analysis approach is found to be more sensitive than the other two approaches. This approach provides a compact description of the second moment properties for stochastic versions of a constructed econometric model. It should also be noted that in contrast to the spectral simulation approach employed by Naylor, et al., a spectral analytical approach is possible.[35] This latter method involves characterizing the stochastic response of the analytical solution to a system of difference equations representing the econometric model. That is, it allows us to derive the stochastic properties directly from the model. One of the principal advantages of this approach is that its results are not subject to sampling variability, a property of simulation results which is often difficult to interpret. Furthemore, replications of stochastic model solutions (as in the case of stochastic simulations) are not required and the analytical approach provides a relatively simple means of examining alternative functional forms and parameter estimates.[36]

The Candler and Cartwright [1969] study is substantially different than those outlined above. It is somewhat similar to the Zusman and Amiad [1965] investigation except that here the objective is to estimate the performance surface throughout the space corresponding to selected ranges of the variables or factors. They desire relationships which will capture the impact of specific assumptions regarding these variables on resulting outcomes. Given a completed budgeting or simulation examination, the problem is to derive these more general and explicit functional relationships between decision variables, structural parameters and performance statistics. On the basis of these functions, outcomes or performance measures can be estimated directly without resource to additional budgeting or simulation examinations. The study is not one of direct optimization but rather estimation of the components entering the objective function which are associated with particular levels of the decision and exogenous variables.

The use of experimental design procedures are emphasized and second order polynomials are utilized to approximate the performance surfaces. Since relative weights attached to multiple performance statistics are not specified, a separate function is estimated for each performance statistic that may enter the ultimate objective function. As indicated in Table IV, a central composite experimental design is utilized to yield--"small magnitudes of residual sums of squares when the function to be fitted is given and the number of observations is fixed" Candler and Cartwright (1969, p. 163). The suggested procedures are applied to a budgetary study of the potential for increased sheep production in a county of New Zealand. Three performance functions containing 15 unknown coefficients are estimated in terms of four variables. Twenty-five "treatment combinations" are investigated. Hence, ten degrees of freedom are available for each estimated function. The resulting estimated performance functions allow determination of (i) performance statistics for any reasonable values of the specified variables, (ii) the sensitivity of performance statistics to marginal changes in the specified variables, and (iii) the combination of the specified variables which yields particular outcomes, e.g., location of break-even points. The principal limitation of the suggested technique is that the number of simulation examinations required to estimate the performance responses increases rapidly as the number of independent variables and/or the degree of the approximate polynomial functions utilized increase.

AGGREGATE MODELS

The models which appear in this classification, although diverse, can be reasonably characterized as systems representing one or more components of developed agricultural sector economies. The models are typically highly aggregative and refer almost totally to the U.S. agricultural sector.[37] Most are constructed to examine the quantitative effects of various governmental policies, e.g., price supports, governmental inventory purchases, acreage allotments and diversion programs, government payments, etc. The agricultural sector systems examined are usually decomposed into a number of components or subsystems and a fragmentary or building block approach is employed in the construction of the models. Although the principal components of these models vary, they are generally concerned with supply and demand for various products and in some cases agricultural input or resource levels as well as nonagricultural economy representations. A number of other aggregate components are often included such as farm income which are recursive to and derived from these basic components.

As indicated in Table V, most of the models are specifically developed for decision purposes while some are concerned with forecasting applications. For the decision applications, only the study by Shechter and Heady [1970] operates with an explicit criterion function.[38] The remaining investigations employ implicit objective functions (reflected by the specified performance variables and the levels of the control or policy variables examined) and, thus, only policy simulation experiments are conducted. Most of the models are dynamic, nonhistorical and incorporate feedback mechanisms in a (stepwise) recursive fashion. Although the models are generally nonlinear, the departures from (intrinsic) linearity are small. Given these weak departures and the recursive nature of the constructed models, the derivation of the reduced forms or the generation of the endogenous variables from the structural form is reasonably simple. Moreover, most all of the models are investigated in their deterministic or expected value form. Hence, the experimental designs utilized for the simulation examinations are typically nonexistent (AD) or pedestrian (BD). Furthermore, none of the investigations represented employ detailed verification procedures. Few formal tests or descriptive measures are advanced in attempts to validate these aggregate models.

TABLE V

Tabular Survey of Aggregate Simulation Models in Agricultural Economics

eferences	Objectives	Components	Decision variables	Model characteristics: Dynamic	Stochastic	Non-linear	Verification	Model application1/	Experimental design2/	Computer language3/
hen, [1970]	To develop an agricultural sub-model for the U.S. economy as a market sector simulator for forecasting sales of a major farm equipment manufacturer	Supply and demand for ten commodity classes (simultaneous), supply responses of crops (recursive), corporate forecasting system	Production levels, marketings, inventory control, financial planning	x		x		DM	AD	FL
dwards, [1970]	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.	Two regions each having employment, income and population growth components	Migration levels, population growth, and worker productivity levels	x		x		FM	BD	FL
Edw[illegible] and De Pass, [1971]	To use a simulation model to project rural-urban population, income and employment for the U.S. through 2020	Urban, rural	Policies designed to increase job opportunities, labor productivity, reduce natural rate of population growth, limit out migration	x		x		DM	BD	FL
Lin and Heady, [1971]	To investigate if slower technical change or more reliance on free markets would have lessened overcapacity and raised income for U.S. farms	Commodity markets, resource markets, production, income	Government farm programs on prices, income, and resource employment	x				DM	BD	FL
McFarquhar and [illegible]s, [19[illegible]	To project changes in production and consumption of food and agricultural products in the U.K. between 1968 and 1975	Consumption, agricultural supply, input-output model, wheat, barley, cattle, sheep	Production levels, sales and purchases, E.E.C. participation of U.K.	x		x		FM	BD	FL
Schaller, [1968]	To outline the research on a national economic model of production response developed by the Farm Production Economics Division, Economic Research Service	Production response, input-output, equilibrium	Production levels, diversion program, allotments	x				DM	AD	FL
Shechter and Heady, [1970]	To apply simulation models in deriving response surfaces for policy analysis in the feed-livestock sector	Micro level (individual firm units), macro level (aggregate out-put variables of all firms)	Minimum acreage diversion, national price support, payment and loan rates, diversion payment rate		x	x		DM	ED	FL

TABLE V (Con't.)

Tabular Survey of Aggregate Simulation
Models in Agricultural Economics

eferences	Objectives	Components	Decision variables	Model characteristics: Dynamic	Sto-chastic	Non-linear	Veri-fica-tion	Model applica-tion1/	Experimental design2/	Computer langu-age3/
yner, 1967]	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	Input, output, market, farm financial, nonfarm sector	Government programs as listed under objective	x		x		DM	BD	FL
yner and weeten, 1968]	To present a methodology that can be used to study issues of farm-nonfarm interaction	Input, output, market, farm financial, nonfarm sector	Government payments to farmers, diversions of cropland	x		x		DM	BD	FL

See Table III for footnotes 1, 2, and 3.

in attempts to validate these aggregate models.

Turning to specific applications, we select for further discussion the works of Tyner [1967], Lin and Heady [1971], Edwards and DePass [1971], McFarquhar and Evans [1971], and Shechter and Heady [1970]. The Tyner [1967] study forms the basis for the results reported in Tyner and Tweeten [1968] and is similar in nature and scope to the Lin and Heady [1971] model. Both models are (stepwise) recursive, the equations of which are estimated ordinary or autoregressive least squares. Each of the two studies emphasize the resource or input as well as farm income components of the U.S. agricultural sector. Both examine via simple simulation experiments the effects of the elimination of all governmental programs, and the rate of technological change. Only the Tyner study explicitly investigates the influence of the non-farm sector on the U.S. agricultural sector by introducing selected changes in employment, disposable income, and input prices. The output or commodity components of the two models in question are represented by a single aggregate production, supply (or marketings) and demand set of equations. As expected these studies suggest that (i) slower rates of technical change would have modest effects on the demand for farm machinery and the migration of labor from agriculture but would increase the level of net farm income; and (ii) the absence of government program or the existence of free market conditions is associated with increased investment in farm machinery, greater levels of off farm migration, reduced farm income, and larger farm sizes.

The model constructed for the U.K. by McFarquhar and Evans [1971] is similar to the above two models but involves far more detail. The three principal components of the model--demand, intermediate and primary demands, and supply--are treated recursively and each component is simulated separately. The first component, the demand or consumer expenditure subsystem, encompasses 27 food products and one non-food product which are estimated by ordinary least squares. The intermediate and primary demand components is composed of 39 agricultural and nonagricultural input products which are related to the outputs of products consumed as food. This component is constructed as an input-output model assuming constant technology. The supply component is treated as four subsystems which revolve around the 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 U.K. entry into the European Economic Community (EEC) along associated price and import policies. One of the major conclusions of the study is that joining the EEC will result in increased expenditures on food. Although the model is reasonably complex, the experimental design and verification procedures are naive. Moreover, the stochastic properties of the model are neglected when the forecasting applications are performed.

The model constructed by Edwards and DePass [1971] is of a different nature than those discussed above and is basically the same as that reported in Edwards [1970]. Their concern is with the distribution of population, income, and employment across rural and urban sectors. Hence, the model consists of U.S. rural and urban components. Given the difficulty of isolating these two major components on an aggregate U.S. basis, four alternative and basically arbitrary delineations were examined. The simulation results for these four delineations were found to be invariant with respect to general conclusions regarding future prospects. For each of the two components income, employment, and population growth equations are represented while a net migration equation between the two components is specified. The parameters of these seven equations are estimated trial and error, the criterion being the reproduction of 1970 data from the 1960 data for population, income, and employment. Sensitivity analysis is utilized to investigate various parameter changes as well as alternative policies. With respect to the latter, various targets for population, income, and employment were specified and the most 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 a reduction in outmigration or rural population birth rate decreases. In both the model estimation and implementation potential stochastic aspects are neglected. Furthermore, the experimental design and verification procedures utilized are especially naive.

One of the more interesting applications classified under aggregate models is the Shechter and Heady [1970] study. In some respects it proceeds in a similar vein to the investigations found in Candler and Cartwright [1969] and Zusman and Amiad [1965]. The model is based on both micro (individual north and south Iowa farms) and macro (aggregate output variables of all farms) components. The aggregate outputs of the latter component represent the response variables of the simulation experiments.[39] The factor or decision variables of the response surface analysis examined by Shechter and Heady [1970] are the four listed in Table V. Basically, in the first stage of the response surface analysis the shape of the surface is determined (by fitting a first degree polynomial) while in the second stage steepest ascent is used to search for the surface peak (near-stationary region determined by fitting a second order polynomial) or optimum. A complete response surface analysis involving these two stages is not attempted by Shechter and Heady [1970]. Instead, due to the costs of the two stage approach, they combine the first and second stages and fit a second degree polynomial directly. This function will reveal an extreme point on the response surface if such a point exists within the experimental region. If not, the estimated polynomial will at least reveal the general shape of the surface.

The response surface analysis to simulation experiments is emphasized in this paper. The experimental design is partial factorial and optimal search procedures take place in the context of univariate response methods. In particular, for each of the four response variables and their associated surfaces relative maximum or minimum points were discovered. Examining each of these variables independently, it was found that rather large improvements could be made in the design of the system.[40] A multi-response surface for the four performance variables is only implicitly investigated. As previously indicated, weights for the various performance or response variables were not assigned. Hence, in context of a multi-response surface only an efficiency frontier (locus of efficient decision rules examined) is provided. The verification of the underlying micro and macro components representing the real system involves a simple historical comparison of observed and explained values for a few of the systems outputs. Attempts were also made in this study to validate the second degree polynomial approximation of the response surface. For this purpose the lack-of-fit mean square measure (indicating only the amount of variation in the response surface explained by the polynomial approximations) was employed and deemed adequate.

DEVELOPMENT MODELS

Problems of economic development turn out to lend themselves rather well to the systems analysis approach. They are typically eclectic, highly specialized to the particular country under examination. This is presumably due to the institutions as well as a wide diversity in the agricultural industries and of their basically exploratory nature. The eclectic nature of these systems models is illustrated by these models 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 the related restrictions with regard to potential policy variables and objectives. Their exploratory nature derives from the strong pragmatic orientation and a typical dearth of fundamental types of behavioral and technical relationships as well as data which might be employed to identify them.

As a result of this situation with respect to data availability and other problems mentioned in the previous paragraph, the systems models which have been constructed for development studies have some easily identifiable characteristics. To be sure, they generally make substantial use of the components and decomposition possibilities mentioned in section II. Although the level of autonomy of the components as well as the level of aggregation at which they are specified is quite different among models, they are much in evidence. The value of the components approach in studies of this type is based upon team research project possibilities (as typified by the Nigerian study, Johnson, et al., 1971) and the advantage presented for dealing with the problems created by a lack of information. The development models are typically for whole countries or large sectors of countries and, thus, the modelling process requires inputs from a number of researchers (possibly from quite different disciplines) and/or agencies. The components aspect of construction provides a convenient vehicle for facilitating the needed cooperation of the various parties in the formulation of the systems model. Implications of the components approach as they relate to the information problem are rather obvious. The approach permits the independent assembly and usually reassembly of pertinent information. Moreover, adjustments in the structure of the model which are necessitated by the availability of new information on data seem to be more easily accommodated. Relatedly, the components approach also has some desirable aspects with respect to verification or validation possibilities. As will be apparent from the commentary, however, these attributes of the method have, thus far, been used only to a limited extent.

A second characteristic of these models involves their theoretical underpinnings. With few exceptions--notably those by Day and Singh (1971, 1972)--the models are specified at aggregate levels. That is, they are specified at industry, regional or sectoral levels. As a consequence, the models are descriptive in nature; being frequently specified more on the basis of observation of the particular economies than more established theories. This characteristic of the models adds substantially to verifiability or validation problems. As mentioned above, data are limited in quantity and quality. This problem is further complicated by the multitude of alternative hypotheses associated with the specified structural models. Partly as a result of this verification problem but also due to the interest of the various international agencies in utilizing the models for planning, there seems to be considerably more interaction between the model builders and model users in this area than in the others surveyed. In this respect then the methods and procedures appear more similar in spirit to the industrial dynamics method (Forrester, 1961) than to traditional models of economic systems.

As previously mentioned, the various economic development models can be viewed as industry, regional or more aggregated sectoral and economy models. The agricultural sectoral and economy models are those by Halter, et al., (1970), Holland (1962), Johnson, et al., (1971), Taylor (1969), Manetsch (1972), Holland and Gillespie (1963), and Kresge (1967). Along with these models we also include those by Billingsley and Norvell (1971) and Foster and Yost (1969). The latter two studies are not sectoral or economy models but are similar in terms of method and represent an interesting extension of the systems method to problems which are of strategic importance in developing economies. Of the previously listed sectoral or economy models, those by Holland (1962), Holland and Gillespie (1963), and Kresge (1967) are noteworthy for two reasons. First, and most importantly they represent initial applications of the system method (as modernly conceived) to development planning. Secondly, they have a nonagricultural orientation. Although the methods employed in constructing these systems models and in designing the policy simulations are somewhat less advanced than those treated in some of the subsequent models, they in no way minimize the contribution embodied in these pioneering works.

The sectoral models identified with the systems modelling work at Michigan State University are by Halter (1970), Johnson, et al., (1971) and Manetsch (1972). These studies are reports on massive systems modelling efforts in Nigeria and Korea. The systems models are very complex and extensive by comparison to those employed or constructed for any of the areas represented in this survey. As a consequence of the size of the systems models, the components concepts mentioned above were advantageously used. The methods of model formulation, estimation and simulation are not innovative by the standards set down in the first four sections of our discussion. However, this is not expected in the sort of situation in which the model was constructed and simulated. The encouraging aspects of the endeavor involve possibilities for adapting the software for work with other economies--see Manetsch (1972)--and the fact that the officialdom of Nigeria appear to be utilizing the results--perhaps the ultimate verification test. The remaining model, that of Taylor (1969) is an interesting application of model formulation and estimation. It is a systems model which is tied quite closely to the Domar theory of economic growth for developed countries and is estimated by standard econometric techniques.[41]

The regional model listed in tabular survey Table VI is by Richard Day and I. J. Singh (1971, 1972). The model proposed and applied by these authors is of value in a number of respects. First, it corresponds to a micro firm model and as such has more primitive theoretical underpinnings than any of the models discussed in this section. The model is designed to study the transformation from traditional to commerical agriculture in the Indian Punjab. It is recursive with a number of feedback alternatives involving changes in adaptations of technology, market prices and so on, etc. One of the more interesting aspects of the model is the objective function which involves the specification of several observed firm objectives. The incorporation of these lexicographic types of criteria seems to represent a very promising possibility for closing the gap between the confining theories of individual behavior and the descriptive types of models applied in the development context. A second aspect of this study which is deserving

TABLE VI

Tabular Survey of Economic Development Simulation Models in Agricultural Economics

References	Objectives	Components	Decision variables	Model characteristics: Dynamic	Stochastic	Nonlinear	Verification	Model application1/	Experimental design2/	Computer language3/
Aldabe and Eijckeghen, [1966]	To use simulation for quarterly forecasting of the Argentina cattle stock and its main components	Slaughter, herd death and birth rates	Mortality rates, fertility coefficients, stock levels	x				BM	ED	FL
Billingsley and Norvell, [1971]	To build an economic demographic simulation model to project the economic effects of changing the population growth rate of the Dominican Republic	Fertility, population, gross national product, mortality and birth rates	Government supported fertility control, labor force participation	x		x	x	DM	BD	FL
Day and Singh, [19[illegible]]; Si[illegible] and Day, [1972]	To explain the transition from subsistence, traditional agriculture to commercialized modern agriculture in the Indian Punjab through accounting for strategic details of technology, farm decision making, and the market environment	Farm activities and decision variables within regions, annual objective function, technology matrix, technical constraints representing regional resource limitations, behavioral relations including adaptive mechanisms, feedback functions, exogenously given prices and supplies of variable production factors	Technology adaptation, crop mix, resource expansions	x	x		x	BM	FD	FL
Foster and Yost, [1969]	To study and clarify the relationship between population growth, expenditures on education and economic development in an underdeveloped rural economy	Demographic, educational, income	Resource allocation, schooling, birth, education expenditures	x	x			BM	ED	FL
Hayenga, et al., [1968] and Halter, et al., [1970]	To illustrate the application of simulation as a problem-solving approach to the development of the Nigerian agricultural economy	Regional (southern tree and root crops and northern annual crops and livestock) inputs, production, marketing, consumers, trade, population	Acres cultivated, employment levels, profitability rate of price adjustment, level of productivity	x		x		BM	ED	OL
Holland, [1962]	To examine the problems of economic development and foreign trade policy for an underdeveloped country	Production, export, consumer, capital	Public service, investment allocations and levels	x		x		DM	ED	DL
Holland and Gillespie, [1963]	To report on some exploratory experiments in economic dynamics performed on a simulated underdeveloped economy	Supply, demand, production sectors, capital and investment, import-export	Investment allocation, foreign trade policies, anti-inflation policies, exchange rate and tariff levels	x		x		DM	CD/ED	DL

TABLE VI (Con't.)

Tabular Survey of Economic Development Simulation
Models in Agricultural Economics

ferences	Objectives	Components	Decision variables	Model characteristics: Dynamic	Sto-chastic	Non-linear	Veri-fica-tion	Model applica-tion1/	Experimental design2/	Computer langu-age3/
hnson, et al., 971]	To develop a general system simulation approach for examining agricultural development which is operational	Regional agricultural sectors (northern annual crop-beef model and southern perennial annual crop model), non-farm sectors	Land allocations, level of modernization, marketing board and export tax policies, investment allocation and levels	x	x	x	x	DM	ED	OL
esge, 967]	To present a general simulation model to be used for policy evaluations by developing countries using Pakistan as an example	Final demand, industrial production, income, regions	Level of investment and saving, consumption levels, imports coefficients	x				DM	BD	FL
hker and netsch, 971]	To examine the feasibility of using simulation to analyze the planning of beef production in Northeast Brazil	Nutritional cash crops, herd management, credit	Land use, production levels, sales policies, herd management modernization	x		x	x	DM	ED	FL
netsch, 972]	To describe the role of simulation models in the study of Korean rural development	Agricultural production, regional sectors, urban and rural consumption, population, prices	Policy alternatives: 1) increase of food self-sufficiency and growth of rural income 2) budget reallocation for rural development 3) move the agricultural sector to reliance on competitive markets	x		x		DM	BD	OL
netsch, et ., [1971]	To develop computer simulation program for modernizing cotton production in Northeast Brazil	Production, credit, transportation, processing, marketing, consumption	Research and extension expenditures	x	x	x		DM	ED	FL
net[illegible] nd nchm[illegible] 971]	To develop a simulation model to compute the consequences of alternative development strategies for the Brazilian textile industry	Regions, production cloth type, inputs	Allocation of investment by region and production mode, adoption of technology	x		x		BM	AD	FL
athis, 969]	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	Traditional farms, modern farms, extension, research, disease and pest control, credit, income, marketing and transportation, export and domestic consumption	Development loans, government expenditures, investment	x		x	x	DM	DD	DL

TABLE VI (Con't.)

Tabular Survey of Economic Development Simulation Models in Agricultural Economics

...erences	Objectives	Components	Decision variables	Model characteristics: Dynamic	Model characteristics: Stochastic	Model characteristics: Nonlinear	Verification	Model application1/	Experiment design2/	Computer language3/
...rts and ...ge, ...68]	To explore the interface between the economy of an underdeveloped nation and its transportation system using Columbia as an example	Final demand, industrial production, income, interregional commodity flows, regional output, transportation costs	Choice of transport mode, transportation system, expansion, quality, output levels	x		x		BM	BD	FL
...lor, ...69]	To examine structural change in sectoral output levels during the course of economic growth and to examine the forces underlying these patterns	Input, output, trade, consumption, industry production, primary production, services	Import substitution, government expenditures	x*		x		BM	ED	FL

...e Table III for footnotes 1, 2, and 3.

of special comment is the verification procedures. Not only do the authors include a discussion of formal verification procedures for the model but the procedures themselves--which among other alternatives incorporate some ideas from information theory in comparing observed and predicted series (Day and Singh, 1971, pp. 43-46)--represent potentially productive methods for handling such problems.

The last category, those for industries, includes studies by Aldabe and Rijckegham (1966), Lehker and Manetsch (1971), Manetsch and Lenchner (1971), Manetsch, et al., (1971) and Roberts and Kresge (1968). Aside from the institutional and information problems which are typical in development studies, these works are very much similar to the industry studies reported in the market model survey. The models are typically descriptive, without well defined criterion functions, and designed for studying or forecasting influences of policy actions on industry output price and the like.

With the notable exception of the model by Day and Singh (1971), these systems studies are somewhat deficient in connection with respect to the treatment of verification, the design of policy experiments and response surface examination. The specific characteristics of these systems models and simulations are catalogued in tabular survey Table VI. Having made this statement it is necessary, however, to mention that the studies are exploratory and frequently performed under time constraints and with information bases which are quite small in comparison to the magnitudes of the models. We point out these areas for possible improvement, therefore, not as a criticism of the work already done in the development modelling, but to indicate the potential for refining and improving these studies within the context of the systems analysis and simulation approach.[42]

RESOURCE MODELS

Tabular survey Table VII contains applications of simulation methods to agriculturally related resource problems. The studies surveyed in this table are by no means exhaustive; they are, however, hopefully representative. They refer mostly to water resource or regional economy system oriented investigations. The usual nonlinear feedback characteristics of such systems suggests that simulation methods can be beneficially employed. The major components frequently include reservoirs, flood, demographic, transportation, use sectors, irrigated crop production, and the like. Although these components are often treated recursively, there is typically a substantial amount of interaction and feedback among them.

A number of the applications in this classification are concerned with river basin or watershed systems. Benefit-cost type analyses provides the mode for evaluating alternative policy decisions in these systems. Such decision model applications comprise roughly half of studies recorded in Table VII while the vast majority of the remainder are behavioral model applications. Most of these behavioral model applications are descriptive rather than explanatory in nature. In particular, these latter studies are principally concerned with the development of physical relationships such as those involving natural hydrologic phenomenon.[43]

The various model representations entering this classification are generally dynamic and nonlinear. Some of the nonlinearities involved are fairly substantial including a few time counter relationships. The dynamic structure of these models is often characterized by the inclusion of lagged endogenous (output) and exogenous (input) variables and, thus, is represented by a system of difference equations. Approximately fifty percent of the models are simulated in their stochastic form. These stochastic simulations are typically limited, however, in the sense that only additive stochastic (disturbance) elements are recognized. That is, the stochastic nature of the sampling distributions of the parameter estimates associated with these models are disregarded--only the first moments of these distributions are utilized. It should also be noted that a large number of the conducted stochastic simulations were performed for the physical models representing hydrologic phenomenon.

The simulation experiments for the group of models appearing in Table VII are a bit more sophisticated than most of previous groups of models surveyed. In particular, a large number of the experimental designs utilized are fractional factorial with few naive designs (BD). Some of the designs also involve optimum seeking methods. The verification procedures employed, however, are less precise. Only seven of the studies reported proceed beyond graphical comparisons of sample or historical and simulated values of selected output variables. The predictive properties of the constructed models are typically neglected in attempts to validate the representations of the system in question.

The models specified in Halter and Miller [1966], Hufsmidt and Fiering [1966], Hamilton, et al., [1969], Rausser, et al., [1972], Jacoby, [1967], Dudley, et al., [1972], and Chow and Kareliotis [1970] are regarded as representative of this group of models and, thus, are selected for further discussion. The first three mentioned models are all concerned with river basin systems. The Halter and Miller model represents and earlier application of industrial dynamics and the DYNAMO computer

Tabular Survey of Resource Simulation Models in Agricultural Economics

References	Objectives	Components	Decision variables	Model characteristics: Dynamic	Model characteristics: Sto-chastic	Model characteristics: Non-linear	Veri-fica-tion	Model applica-tion1/	Experimental design2/	Compute langu-age3/
Anderson and Hass, [1971]	To develop and test procedures by which operators and builders of irrigation systems can compare and evaluate alternative methods of distributing water among farmers	Production benefits, water allocation, water supply	Crop levels, water sequencing, operating procedure to deliver water, selection of crops to be irrigated	x		x		DM	ED	FL
Askew, et al., [1971]	To simulate critical periods of drought to assist in the planning and construction of reservoirs and to compare generating techniques	Rivers, stream flow	Maximum permissible extraction rate, duration of low stream flow and the accumulated deficiency relative to the mean flow	x	x	x	x	EM	ED	FL
Chen, [1971]	Develop a costing procedure which will be practical and useful tool in planning of cottage resorts	Investment, cost	Type of accommodations, secondary business facilities, and outdoor recreational facilities, length of season		x		x	EM	ED	FL
Chow and Kareliotis, [1970]	To formulate a mathematical model of a stochastic hydrologic system	Precipitation, runoff, storage	Conceptual watershed storage, stream flow	x	x	x		EM	AD	FL
Dudley, et al., [1972]	To estimate the long-run optimal area to develop for irrigation given the size of a reservoir	Water supply, water demand, crops, moisture, costs	Acreage to be developed for irrigation	x	x	x		DM	BD	FL
Ellis, [1965]	To present a systems model of recreational activity in Michigan that can be utilized to predict the outcome of proposed changes or innovations	Population centers, transportation, destination	Activity by type recreation and location			x		DM	BD	FL
Halter and Miller, [1966]	To test the applicability of simulation in evaluating water resource development projects and to test alternate resource management policies for an actual river basin	Hydrologic flows, upstream and downstream flows, costs, benefits, drainage	Size of proposed reservoir and channel capacity, channel improvements	x	x	x		DM	ED	DL
Hamilton, et al., [1969]	To apply systems simulation to regional analysis, specifically the Susquehanna River Basin	Demographic, employment, water (quantity and quality), spatial	Wage levels, migration levels, worker productivity, population levels	x		x	x	FM	ED	DL

TABLE VII (Con't.)

Tabular Survey of Resource Simulation Models in Agricultural Economics

References	Objectives	Components	Decision variables	Model characteristics: Dynamic	Stochastic	Non-linear	Verification	Model application1/	Experimental design2/	Computer language3/
Hufsmidt, [1963]	To find an optimal design for a given river basin system	Reservoirs, hyro-power plants, irrigation system, flood damage system	Reservoir storage capacity, active and inactive storage capacity, installed capacity at alternative power plant sites, output levels for irrigation water	x	x	x		DM	FD	FL
Hufsmidt and Fiering, [1966]	To outline a procedure for water resource simulation with an application to the Lehigh river basin	Supply of water, demand for water-derived products and services, flood, energy, temporal, benefits	Hydrologic conditions, dam and reservoir capacities, type of irrigation works, size of power plants, levels of flood damage alleviation	x	x	x	x	DM	CD	FL
Huggins and Monke, [1968]	To develop a model to simulate the surface runoff from watersheds by delineating the model to a grid of small, independent elements	Rainfall, runoff	Rainfall interception, infiltration			x	x	BM	AD	FL
Jacoby, [1967]	To develop a model to evaluate major investment and operating decisions for electric power planning using West Pakistan as an example	Costs, agricultural sector, irrigation water, electric power, foreign exchange rates, power demand, spatial markets	Size and location of multi-purpose hyroelectric and irrigation development, operating rules, type of plant	x		x		DM	CD/ED	FL
Leistritz, [1970]	To determine forces that have major influence on farm real estate markets	Supply, demand, farm size	Land purchases, land prices, land rented, rental rates	x		x		BM	ED	FL
Masch, et al., [illegible]	To develop a set of interrelated water-quality models capable of routing water quality parameters through a stream subsystem	Thermal behavior, waste assimilation, routing of conservative minerals, spatial, water quality, runoff	Location of waste loadings and withdrawals	x		x	x	BM	ED	FL
McMahon and Miller, [1971]	To demonstrate the proper use of a first order non-seasonal Markov model with skewed data in the synthetic generation of stream flows	Hydrologic flows	N.A.	x	x	x	x	BM	AD	FL
Miernyk, [1969]	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	Water supply, water demand, spatial, production, agricultural, commercial, industrial, and municipal sectors	Crop production levels, water purchases, water (purification) treatment					FM	ED	FL

TABLE VII (Con't.)

Tabular Survey of Resource Simulation
Models in Agricultural Economics

References	Objectives	Components	Decision variables	Model characteristics			Verification	Model application1/	Experimental design2/	Computer language3/
				Dynamic	Stochastic	Nonlinear				
Pisano, [1968]	To provide a set of options to be used in river basin planning for water quality management	Water quality, streamflows, reservoir levels, pollutant concentrations	Various combinations of reservoir sizes, reservoir releases and waste input schedules, water quality standards	x	x	x	x	EM	ED	FL
Rausser, et al., [1972]	To determine the probability distribution of the external learning benefits emanating from the construction of a water desalting in San Luis Obispo, California and to utilize this information as a basis for public subsidies	Learning desalting plants, costs, external benefits	Public subsidies	x	x	x		DM	DD	FL
Rodríquez-Iturbe, et al., [1971]	To compare various Markovian models with respect to their adequacy in the preservation of the required reservoir storage characteristics of the historical record	Streamflows	Seasonal structure, periodicity, cyclic variation, random filters	x	x	x	x	EM	ED	FL
Shih and Dracup, [1968]	To use a hybrid computer simulation model to solve the three dimensional non-uniform diffusion equation for determining evaporation from finite areas of water	Wind, temperature, humidity, atomospheric pressure	N.A.			x		EM	AD-	FL
[illegible]lson, [illegible]9]	To outline a regional trade model to determine the economic impact of proposed pollution abatement programs for the Western Basin of Lake Erie	Tradeable commodities, untradeable commodities, transportation system, costs, prices, final demand, spatial	Type of abatement program (size and technology), taxes					DM	AD	FL

See Table III for footnotes 1, 2, and 3.

language to water resource development projects. The proposed projects involve the construction of dams and channel improvements in the Calapooia River Basin. Benefits include the value of irrigation, flood control, fishing, and drainage. A particularly interesting aspect of the model development is the treatment of the temporal distribution for hydrologic flows. These flows are generated internally in the model by a random number generator process and considerable care is taken in attempts to assure that the simulated hydrologic data conforms to historical flows. In the simulation analysis which ensues, five alternative dam sizes and three operating rules are investigated. The experimental design utilized appears reasonably simple (ED) with no specific indication as to how the combinations of project size and operating rules were selected and evaluated. Their results suggest that channel improvements are more important in terms of the (implicit) criterion function than increasing reservoir size.

The approach to constructing simulation models for water resource systems detailed in Hufsmidt and Fiering [1966] is more general than the treatment contained in Halter and Miller. The former study presents the various steps and procedures required to institute a simulation program including aspects related to collecting and organizing hydrologic and economic data as well as developing the logic and detailed code for simulation analysis. These procedures are applied to both the Lehigh River Basin and the Delaware River Basin, the former being a subsystem of the latter. An interesting development for synthesizing hydrologic events is provided. Pollution is also considered along with the costs of abatements. A number (three) of alternative criteria are employed to validate the constructed models. For the decision applications, economic consequences (benefits and costs) associated with design variables and outputs are evaluated under several assumed interest rates, static and dynamic investment patterns, as well as methods of discounting benefits and costs. In these applications, an explicit criterion function is specified involving the present value of expected net benefits along with the variance of these benefits. Unfortunately, no computer program or mathematical formulation of the complete model (representing the Delaware River Basin) is presented. Moreover, the experimental procedures employed are presented in a loose framework. A few basic plans are investigated and then, from knowledge accumulated, improvements are made upon the basic plans and the search is continued. However, no specific search procedure is developed in this study.[44]

The third river basin study referred to above and conducted by Hamilton, et al., [1969] contains more of a regional flavor than either of the two previously discussed basin studies. This case study of systems simulation to regional economic and river systems modelling should prove of interest for some years to come.[45] The principal objective of the work is 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 model developed is offered as an attempt to gain a better understanding of regional growth and water resource relationships in the Susquehanna River Basin. The model is composed of three major components that describe the demographic, employment, and water supply characteristics of nine subregions which comprise the river basin. The demographic component representing labor supply and the employment component representing labor demand interact at the subregional level but are separable across the various subregions. The subregional water components are, however, nonseparable since the withdrawals of water or the discharge of waste in one area can influence water in downstream subregions. These subregional components contain aspects of both water quantity and water quality. The principal limitations of the constructed model include the use of employment as the primary indicator of economic activity and the imposition of the 1960-1975 (industry group) growth rates on the 50-year forecast period.

The obviously important features of the systems model constructed by Hamilton, et al., may be characterized as: (i) the inclusion of both demographic and economic components in a single model; (ii) the explicit application of both economic and engineering concepts to regional water resource problems; (iii) the dynamic aspects which are evidenced by feedbacks and lagged variables within the various components as well as between components; (iv) the ability of the model to facilitate sensitivity analysis. One of the more interesting results of the simulation analysis is that the revealed water shortages emanated not from the scarcity of the water resource itself but rather from current water treatment, storage, and distribution systems. Hence, given investments in expanded water systems a sufficient amount of water would be available.

Turning away from river basin systems, a recent study by Rausser, et al., [1972] was advanced in an attempt to determine the level of public subsidies that might be provided for water desalting plants. The basis for these subsidies are the external benefits which emanate from the "learning" process or desalting experience. The experience gained in the construction and operation of a particular desalting plant is presumed to result in more efficient production for other plants constructed in the future.[46] Hence, the purpose of this study is to estimate alternative learning functions for water desalination and investigate their implications for external learning benefits and associated public subsidies to particular water desalting plants.

A "learning by doing" model provides the basis for the specified (non-linear and dynamic) learning functions which are estimated by both Classical and Bayesian methods. In the case of the Bayesian estimates, two alternative families of prior probability density functions are utilized. The first is based on the learning experience of non-desalting industries and the second is based on sample desalting costs of foreign plants. From these estimates as well as some additional information a joint probability distribution which includes external learning benefits is specified. Since it was not possible to derive the marginal density function for such benefits analytically, computer simulation experiments were employed to generate an estimate of this function. In other words, the probability distribution for these benefits were empirically approximated by Monte Carlo methods. These approximate distributions were obtained for alternative plant capacities (six), discount rates (two), expected growth rates (two), expected plant life (two) and estimated learning functions (three). On the basis of these approximated external benefit probability distributions a number of suggestions regarding appropriate levels of public (State and Federal) subsidies are derived.[47]

The model developed by Jacoby [1967] emphasizes alternative investment and operating decisions for electric power plants in West Pakistan. More specifically, the model analyzes potential investment in generation facilities for each of several electric power markets. Each plan must satisfy predetermined power demands and has an associated temporal pattern of operating costs. An attempt is made with some success to examine electric power planning from a systems view rather than project-by-project. The computer simulation model utilized generates outputs of various plants, range 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 some of the regions investigated. Site size and timing of plant construction are explicitly treated. The first priority of water is specified to be irrigation uses and the electric power opportunity costs of this priority are evaluated.

The experimental design utilized in Jacoby's simulation analysis involved both multi-stage techniques and partial factorial designs. On the basis of a single basic demand projection, a variety of plans were tested, some of which were eliminated from further analysis. This initial analysis provides a new set of combinations to be investigated. Three examples illustrating the use of these techniques are given. They are: (i) evaluation of power benefits for a large dam, (ii) timing of plant construction, and (iii) alternative dam operating policies. The constructed simulation model is impressive involving a considerable degree of feedback. Unfortunately among other limitations no real attempt is made to verify the constructed model.

The Dudley, et al., [1972] model is a relatively straightforward model in which the purpose is to determine the "best" area size for irrigation. This decision is presumed to take place in conjunction with a reservoir of a 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. In determining the "best" acreage to develop for irrigation the authors incorporate strategies (developed in previous papers[48]) on the combination of irrigated and dryland crop acreage to plant and the allocation of a given quantity of water to an irrigated area over a season.

The actual determination results from simulating over a twenty year period, under both stochastic demand and supply the effects of varying acreages. The acreage for which the largest value of the criterion function is obtained is regarded as the approximate optimal acreage to develop for irrigation. Sensitivity analysis is employed in an attempt to ascertain how the determined acreage would be altered under varying opportunity costs. Opportunity cost as a percentage of original costs are allowed to range from 50 percent to 150 percent. Quadratic functions (for each of the specified levels of opportunity costs) relating net revenue to irrigable acreages are also estimated and the penalty for employing suboptimal acreages is computed. No attempt to verify the constructed model is advanced and the experimental design utilized is simple. Two of the more important limitations of the analysis are the assumption of constant between season dryland yields and the failure to consider storing water in the current year to augment available supply in future years.

As previously indicated, a number of the studies represented in Table VII refer to physical models concerned with hyrologic phenomenon. The Chow and Kareliotis, [1970] model is representative of these analyses and is briefly elaborated upon here. Their hydrologic model is formulated in the context of a watershed system and is 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: (i) groundwater storage, (ii) total rainfall, and (iii) total losses. Three alternative models for these processes are compared and evaluated. These models are basically a moving average, sum of harmonics, and an autoregressive model. In selecting among these models the non-nested nature of the hypotheses (or the disparate families of hypotheses) represented by the alternative model representations is not recognized. Instead the selection is based upon the correlogram and spectral analysis. All three runoff components are found to exhibit correlograms oscillating without any indication of dampening. This along with the power spectrum of the sample data revealing significant peaks for six month and annual periods resulted in the selection of a combined sum of harmonics and autoregressive time series model representation. This selected model is then employed to simulate the runoff processes. The principal limitations of the analysis are: the validation of the constructed simulation model is lacking; the feedback among and between the various components is not particularly strong; and the experimental design approach is deficient.

VI. CRITIQUE AND APPRAISAL

The comments in the survey section along with the framework provided by the previous discussion suggest a number of observations with regard to the current and potential value of systems analysis concepts for teaching and research in Agricultural Economics. Some of these observations have, in fact, already been anticipated in the commentary of the survey section. In this section the arguments are formalized and assessed in terms of possible implications for the profession.

One aspect of the studies which comes through rather clearly in the survey is a rather general departure from the neoclassical theory. This seems to be true in the decision as well as in the more descriptive or behavioral and forecasting model applications. In most cases this departure does not appear to represent a rejection of the theory. Instead it seems to be associated with the types of systems being modelled and an inavailability of sufficient theoretical results. Guidelines from the theory are commonly employed for suggesting variables entering structural relations and possible criteria for decision models. However, it becomes reasonably clear that the dynamic, aggregate and uncertain nature of many of the problems requiring the attention of the profession is not fully embraced by the theory. In short, we are left with the impression that the users of the systems approach--whether for educational or research purposes--are engaged in a heuristic excerise; continually formulating and reformulating the models as new information in the form of improved theoretical concepts or observations on the system becomes available.

The preceding assertion is enhanced once we recall that the systems being modelled are frequently ones for which there is a dirth of observed information.

As a consequence, the systems models themselves are employed to generate results used for indicating appropriate types and amounts of information to collect and, in fact, in generating information on the systems themselves (Forrester, 1961). Thus in decision as well as in behavioral and forecasting models we find ourselves proceeding adaptively--formulating models of systems, refining their theoretical basis, gathering information, reformulating and etc.,--with the ultimate end of improving upon the preception and representation of the system being modelled.[49]

A second noteworthy characteristic of the models is associated with the methods by which information is generated for estimating structures of forecasting, behavioral and decision models and, relatedly, the methods employed in the "solution" of decision models. In brief, these methods are commonly rather haphazard involving a lack of improvement criteria and, as mentioned in section III, an absence of efficient experimental designs, whether for isolating response surfaces of structural models or for numerically approximating optima for the various types of decision or policy models. That is, the process of solution and/or systems model improvement typically takes place within a very general or unspecified basis for control.

The key words in these introductory comments are, of course, adaptive and control. In short, all of the studies which involve the systems approach can be viewed as a type of adaptive control process. For the descriptive or behavioral and forecasting model applications the process is reasonably straightforward. The objective, as generally stated, is the one of improving the characterization of the system. In this case the control variables of potential importance are principally concerned with the design of data gathering experiments whether conducted within the real system--in which case the usual types of sampling criteria are of importance--or within the systems model--in which case we are concerned with identifying the response surface so as to determine the internal workings of the model. In the decision models the problem is somewhat more complex. If the structure is taken as known or invariant to new information, then the control problem posed is simply one of attaining the policy objectives. Although numerical approximations of complicated objective functions and/or complex structural models may be difficult, the optimization process is, in principle, possible. When the characterization of the structure is not invariant to new information, however, the control problem for decision problems becomes considerably more complex. Clearly, if the system is operated on the basis of the solution to the model, then the policy followed influences the type of new information obtained for improving upon the characterization of the system. Since the solution to the policy problem will usually be improved if the structure is known with more reliability and the quality of information for improving the structure is contingent upon the policy followed, it is clear that there are dual considerations in setting optimal policies. Adaptive optimizing problems of this type are known as dual control problems.

The availability of solution algorithms for adaptive and/or dual control problems is currently quite limited. However, this conceptualization of the process of systems analysis can serve some useful purposes. To begin, it provides a unifying methodological framework for viewing the widely diverse types of systems modelling work, thereby, giving a basis for evaluating methods employed as well as methods developments in the whole range of applied situations. The control framework is also of value as an optimizing basis for model construction and operation. This optimizing basis is, of course, very useful in attempting to systematize procedures for the estimation of parameters entering structural models and for simulating or experimenting with the models whether in a policy or forecasting context.

In the following two subsections we review the promising developments in systems modelling as they relate to this adaptive control framework and then attempt to assess the implications of this view of the systems method for research and teaching efforts. Although the first is principally orientated towards methods developments, there are a number of important works in Agricultural Economics which have either implicitly or explicitly applied the approach to be advocated. Where appropriate then, these studies are noted both as a basis for indicating the contributions of Agricultural Economics to methods developments and to illustrate the usefulness of the concepts in applied situations of the type which characterize our more usual research and teaching efforts.

If the conclusion as to the appropriateness of the adaptive control framework for systems analysis is accepted, then there are a number of interesting implications as to how we should train our students as well as retrain ourselves for future research efforts. In the second subsection we speculate on a number of these issues--including the importance of economic theory, mathematical and other technical requirements for handling the approach and finally some methodological questions suggested by viewing the development of applied research results as a control process.

PROMISING DEVELOPMENTS

In this section those aspects of the systems analysis and simulation approach which appear to represent methods for improving the potential of Agricultural Economics research are mentioned. In most cases these are developments which have seen limited, if any, application in the profession. Hence, in addition to discussing the salient aspects of the various developments we shall attempt to indicate research areas where they appear to have the largest benefits.

As suggested in the introductory comments, the more promising aspects of systems analysis are identified with the view that the approach can be treated as an application of adaptive control theory (Burt, 1969). This framework is sufficiently general to encompass both decision or forecasting models and, more generally, the allocation problem presented by the search for more representative behavioral or descriptive models. Since most of the promising developments follow from this view of the systems analysis process, we digress for a short discussion of the elements of control as well as adaptive control theory.

The Control Problem

Control problems are typically dynamic or sequential optimization problems. As such they involve a criterion function in the endogenous (and possibly exogenous variables) and a structure relating the values of the endogenous to the controllable and uncontrollable exogenous variables. Although the relationships involved need, in principle, not to be expressible as mathematical functions, we shall do so for purposes of convenience. More precisely then, if we denote the within period criterion functions as $f[y(t), c(t), x(t)]$ where $y(t)$ and $x(t)$ are respectively appropriate elements of the state or endogenous variables and included uncontrollable exogenous variables, $c(t)$ is the vector of control variables and $g\{f[y(t), c(t), x(t), t]\}$ as the functional defining the criterion function at any point in continuous time, the objective function for the control problem can be written as,

$$W = \int_0^T g\{f[y(t), c(t), x(t), t]\}\, dt.$$

The control theory problem is to optimize this functional W, subject to the conditions relating the state variables $y(t)$, lagged values for $y(t-1)$, the control variables $c(t)$ and other exogenous variables $x(t)$, the initial conditions, and two mathematical conditions specifying boundedness on $y(t)$ and control variables $c(t)$. That is, W is maximized subject to,

$$\frac{dy}{dt} = \dot{y} = h[y(t), y(t-1), x(t), c(t), t].$$

$$y(0) = \bar{y}(0), Y(t) \varepsilon y(t), \text{ and } c(t) \varepsilon C(t),$$

where $y(t)$ is a set of feasible values for the state vectors and $C(t)$ is a set of feasible values for the controls. The parenthetical (t) indicates that in each case these spaces may be functions of t.

The control problem as specified above is nonstochastic. From the previous discussion on systems analysis it would appear that if the approach is to be viewed as a control process, then some provision must be made for accommodating uncertainty. This uncertainty as to structure and possibly criteria is incorporated in terms of probability distributions on the parameters. In particular, when parameter uncertainty is recognized, two approaches to the control problem are possible. The first, which we may denote as a stochastic control problem, presumes the random variables (exogenous variables, parameters, and disturbance terms) have probability distributions which are known. The second, commonly referred to as an adaptive control problem, supposes that the probability distribution functions associated with such random variables are themselves not known with certainty. The first control problem is invariant to sequences of new information while the second uses new information generated by the system to re-evaluate the estimated probability distribution functions. More precisely, in each period the new sample information generated in the previous period is utilized to update estimates of say the first and second moments of the probability distributions. These updated estimates are then used to determine actions in the current period, and etc.

The adaptive control approach is the more realistic of the two approaches to the uncertainty problem and allows a higher expected level of performance than the stochastic control approach. In short, superior information permits attainment of higher levels of achievement in accordance with the specified criterion functions. In this context, an attempt to achieve optimal control policy for several future periods involves both learning and design considerations. How much we learn about unknown parameter values or their probability distributions depends on policy actions, a design-of-experiments consideration. The adaptive control solution to a multiperiod problem then attempts to provide an optimal sequence of actions that consider control, learning, and experimental design. In other words, the choice of optimal control decisions in an adaptive framework is concerned with the dual effects of decisions on control of the economic system as well as future streams of information. The value of such an approach have been outlined by Freebairn and Rausser (1972), Prescott (1967, 1971), and Zellner (1971). In particular, Prescott's findings indicate the importance of allowing for parameter uncertainty in solving control problems, especially when parameter estimates are imprecise.

Adaptive Decision Models

Since economics is a decision science, it follows that many systems models constructed for analyzing economic problems include a decision dimension. That is, according to our discussion in section III many of the models reviewed in survey section (V) could be properly classified as decision models. Moreover, the fact that the analyses proceed in a systems context would suggest some uncertainty as to the structure of the decision problems as well as the values of the parameters which make them specific to particular economic agents (or groups of agents). The narratives in the papers frequently indicate that substantial feedback has occurred between the processes of problem identification, model construction, verification, and policy analysis (see for example Halter, et al., 1970). In short, systems models of decision problems are typically constructed in an adaptive manner with numerous revisions of the structure as new information becomes available. This procedure for model construction and policy analysis can, therefore, easily be viewed as an adaptive control process.

What then is to be gained from this observation as to the similarity of systems modelling of decision problems and adaptive control processes? First, it provides a unifying conceptual basis for viewing the various systems models of decision processes. This unifying basis would seem to be a necessary condition for the development of more systematic and reproducible procedures for the construction and application of systems models and for interpreting results of such analyses as they relate to policy. Secondly, it suggests a basis for evaluating the process of model revision. Systems models are commonly presented as the result of a process which has included numerous policy experiments and related model revisions. The experiments have somehow provided information as to the appropriate structure for the decision problem. The control problem conceptualization then represents a framework within which a systematized and formal rationale for these types of procedures in the formulation and application of decision models can be accommodated.

Lastly, the control framework as "system" for viewing systems models of decision problems has some important implications for the design of policy simulations experiments. As the abbreviated discussion of control problems indicated, experiments with such models have dual objectives--one of providing additional information on the structure, the other of providing information as to the optimal settings of the control variables in connection with the within-period objective function. Thus the explicit recognition of those constructions on the analysis of systems models reaffirms earlier comments with respect to the importance and applicability of experimental design in the simulating process for such models.

Simulation and Preposterior Analysis

As Agricultural Economics is an applied discipline, we must be concerned with problems of estimating response functions (usually technical) for use in the analysis of resource allocation problems. Given the preoccupation with resource allocation problems, it is rather surprising that it has been only recently observed in a formal sense that attempts to capture more reliable estimates of parameters are themselves resource allocation problems of a very traditional nature. Hence, the process of estimating response functions can be viewed as a type of control problem. The criterion in such problems is implicitly a functional in the within period gains (benefits over costs) accruing as a result of the experiment. The structure is given by the nature of the function to be estimated. Control variables then relate to alternatives in terms of experimental design and the extent of experimentation. In an applied context a difficulty with this essentially Bayesian framework for viewing the process of experimental response surface estimation is that the additional information provided by the experimentation is not known until the experiment is conducted. More specifically, if the process is perceived in a Bayesian context (with posterior parameter distributions at one point in time becoming prior distributions in the subsequent period) then the revised parameter estimates cannot be known until the posterior distributions are calculated. A very promising approach to this problem has been recently applied by Anderson and Dillon (1968).[50] 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. The term coined for experimental examinations of this type is preposterior analysis (Anderson and Dillon, 1968).

Simulations of systems models constructed for examinations of this sort can be quite useful in providing information as to the potential of additional nonsynthetic experimental information. This is especially evident in the context of traditional response surface estimation problems. They are also of value in giving guidelines for the design of experiments advanced to examine the likely contribution of additional nonsynthetic information or sample data. In a broader context these methods would also seem to be applicable to situations in which exploratory research is being conducted for the purpose of developing useful descriptive and/or behavioral structural models of economic systems. In this sense the use of simulated data in the development and refinement of economic models is quite consistent with the adaptive control framework.

Possible simulation applications as a basis for preposterior analysis of estimation problems confronted in the construction response surfaces as well as behavioral and descriptive economic models are wide ranging. The advantages of the approach for more traditional response surface research should be obvious from our previous discussion and are nicely illustrated by Anderson and Dillon (1968). For the case of research on the structure of economic models the process is somewhat more complicated. The complications arise in connection with the identification of appropriate criterion functions, the difficulties of interpreting simulated data from models of this type when multiple-responses are present (the usual situation) and the connection between this type of exploratory development of such models and the underlying theory. Although the above mentioned problems are at present limiting in terms of the operational nature of this approach to the development economic systems models, its appeal as a method for systematically utilizing synthetically generated data commends it as an alternative to be considered in the application of systems and simulation analysis in Agricultural Economics research.

Artificial Intelligence and Heuristic Methods

It would be inappropriate to omit from a discussion of promising developments the possible applications of simulation concepts in the development of artificial intelligence methods. Such methods involve attempts to simulate decision maker's or problem solver's thought or discovery processes, rules of thumb applied to complex real world systems, intelligent behavior, and effective problem solving or search methods. They may be thought of as embracing a philosophy for approaching problems rather than constituting an organized and definable set of techniques. For many problems which cannot be solved by classic mathematical and statistical models, these methods are especially useful and involve attempts to move towards optimum solution procedures rather than optimal solutions (Kuehn and Hamburger, 1963). Artificial intelligence is characterized by ~~Meir~~ Meier, *et al.*, (1969, p. 150) 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 to accomplish such items as search, pattern recognition, and organization planning.[51] In a more sophisticated setting it may also include learning and inductive inference.

Although uses of systems models, simulation, and allied techniques as means for generating information about economic systems were suggested fairly early (Simon and Norvell, 1958, Shubik, 1960, Clarkson, 1962), the related heuristic programming and learning constructs have been given little attention by Agricultural Economists to date. To be sure, the process of constructing and simulating any model of a system can be loosely viewed as a process of developing artificial intelligence. The assertion as to the apparent lack of associated applications is, therefore, inferred mainly from the absence of more formal considerations regarding the process.

The simplest of decision problems in applied economics are characterized by a complexity of alternatives with respect to structure and potential decision variables. Learning about or understanding such systems may, therefore, be realistically viewed as a sequential process. That is, we begin with a rough idea of how the system operates and then by procedures similar to heuristic programming we develop models which hopefully perform adequately for the purposes intended. The connection of this process with the theory of learning (Bush and Estes, 1959) should be apparent. Simulation and systems analysis then, by virtue of the comparative ease with which one can heuristically model or program a system, represent valuable tools for enhancing exploratory research efforts.

Even though heuristic programming and related applications of learning theory have been more popular in the study of games (Shubik, 1960), it should be clear that they have wide applicability in the types of exploratory research associated with the various types of eclectic models employed by Agricultural Economists. Moreover, learning theory from an economic point of view and in relation to decision models is, in essence, an allocation problem. As such the applications of heuristic programming and the generation of artificial intelligence fit rather nicely with the overall control theory framework. The previous comments involving the use of synthetically generated data and preposterior analysis present a formal basis on which learning about economic structures and, relatedly, technical response surfaces can proceed. In a more decision orientated context the dual problems of adaptive control processes provide a framework within which exploratory models and policies can be developed.

Opportunities for advantageously applying artificial intelligence in Agricultural Economics research are substantial. In addition to those which would naturally be anticipated on the basis of the previous discussion, there are areas in which these methods have more specific possibilities for application. The area to which we specifically refer is experimental economics (Castro and Weingartern, 1970, MacCrimmon and Tota, 1969, Naylor, 1972, Smith, 1962, 1965 and Watts, 1969. Most of these studies are, of course, closely connected with the gaming models in which the learning and heuristic programming methods found their initial applications. Few propositions of even the more traditional economic theories of individual behavior have been subjected to tests by controlled experiments. The few tests available refer mostly to the equilibriating process of simple competitive markets. If viewed in comparison to other social sciences where theoretical foundations are not terribly rich, this is a particularly striking statement. It seems, therefore, that applications of these systems methods in obtaining information about how agents learn and operate within various economic systems would have substantial potential in Agricultural Economics research. That is, simulation methods could be advantageously applied to generate artificial intelligence about the behavior of agents in the industry. Some initial efforts in this direction were mentioned with respect to the gaming literature in section V. Our purpose here, however, has been to suggest that there are sound reasons for substantially expanding these presently rather limited efforts.

FORECASTING AND PROJECTIONS

In the above discussion on promising developments forecasting problems were indicated as a special type of decision problem. Although this characterization of forecasting and projection problems is essentially correct, they are tasks of Agricultural Economists which are sufficiently important that we single them out for this special treatment. An important function of our applied discipline is obviously to provide agents of industry and government with accurate forecasts and projections. The amount of resources currently devoted to the development of outlook and situation reports, in fact, attests to the importance of these functions.

Systems analysis and simulation concepts can serve a useful function in the development of forecasts and projections. To date, they have provided a vehicle for reconciling the forecasts (which are typically based on classical statistical procedures involving the structures and data) with substantial elements of judgmental input. The possibilities for extension and formalization of these methods are very encouraging. To begin, as our earlier comments have suggested, the formal structure within which the judgmental projections and more classical forecasting procedures can be profitably viewed is Bayesian (Zellner and Chetty, 1965). Moreover, if these alternatives are viewed in a Bayesian framework system and simulation methods can be utilized in solving some of the numerical problems such as providing useful approximations to analytical solutions. To be sure, the use of simulation or more informatively numerical types of experiments must be accompanied by appropriate concern with both the formal structure of forecasting problems as well as associated problems of experimental design. It is also useful to view the forecasting problems which are sequential in nature as a type of control process.

A second and less developed area in which well designed experiments appear to have substantial potential for enhancing research efforts is with regard to estimation of the unknown parameters entering the systems models. More specifically, when projections or forecasts are the basis for policy choices there is increasing evidence that the underlying estimation should be based on loss functions derived from the criterion functions of the decision models (Fisher, 1962). Although this is conceptually a very appealing approach to forecasting problems and the associated development of more specialized outlook and situation information, the computational difficulties of direct solutions to applied problems of this sort are presently forbidding. Systems analysis and simulation methods if viewed in an exploratory context would, therefore, seem to present a useful means of developing new approaches to forecasting and projection problems.

A last area in which systems and simulation concepts have potential for application is related to the analysis of problems which arise as a result of attempts to obtain forecasted values from complex (nonlinear) structural models. These methods appear to have received the most extensive application in developing large scale macroeconometric model forecasts, (Dhrymes, et al., 1972 and Naylor, 1970). Even though the systems and simulation techniques are not as useful as they were once thought to be for the development of such forecasts, they remain a practical alternative for the more complex (both in terms of nonlinearities and complicated stochastic assumptions) of these models (Rausser and Johnson, 1972). It is also worth mentioning that the application of simulation methods to these problems in some respects served to foster the development of analytical based procedures which now permit the more effective use of these models for forecasting purposes.

IMPLICATIONS FOR THE PROFESSION

If the above perceived relationships between modern control theory and systems analysis are correct, then we may anticipate some rather substantial adjustments in both the subject matter and the methods involved in our research and teaching efforts. It appears that contrary to some rather widely held opinions, the advent of systems and simulation concepts have not freed us from our previous preoccupation with economic theory and quantitative methods. That is, rather than allow researchers to circumvent some more traditional areas of training in quantitative methods and theory, the more advanced aspects of systems and simulation analysis suggests even stronger backgrounds in these areas would be beneficial. It should be patently obvious that a knowledge of computer programming or some special simulation language is not a license for conducting effective research in Agricultural Economics. The statistical and theoretical questions raised by the construction and application of systems models are of such magnitude that the usefulness of research produced by mechanical applications of the approach can be of little general interest.

Implications of these observations for the training of graduate and undergraduate students and 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 even some of our closely held methodological conventions. As applications of systems models become more systematized, it seems inevitable that additional study of optimization theory (in dynamic and stochastic contexts) and Bayesian statistical methods will become more commonplace. 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 1950's and 1960's (Johnson, 1971).

The spector of all these changes is 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 these developments to the concepts of systems and systems analysis. The questions raised by the development and application of these 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 hopefully indicated that systems analysis of economic problems is itself in for some rather substantial alterations.

8/11/72

FOOTNOTES

1. We could discuss these terms at length. That will not be necessary since it has been done in general elsewhere, (Churchman, 1968), (Emery, 1969) and in terms of economic models by (Orcutt, 1960). For our purposes it suffices to note that elements may be measurable on non-measurable entities and that relations are defined so as to encompass all types of connections between elements.
2. For example, see (Cohen and Cyert, 1961), (Conway and Maxwell, 1959), (Kotler and Schultz, 1970), (Kuehn, 1962), (McMillan and Gonzales, 1965) and (Naylor, et al., 1966).
3. Along similar lines, see the comments of (Leontief, 1971, p. 5) and (Porter, et al., 1966).
4. These were noticed and capitalized on rather quickly by Agricultural Economists (Babb, 1964), (Babb and Eisgruber, 1966) and (Longsworth, 1969).
5. These attributes of the systems analysis - simulation approach are described, albeit somewhat enthusiastically by (Johnson, et al., 1971, Ch. 3).
6. These limitations are becoming of increasing concern. A general discussion of the limitations which may arise in connection with policy models constructed for agricultural sectoral models is contained in Rausser and Johnson (1972). Similar criticisms have been advanced in a more specialized case by Johnson (1951) and, more generally, by Ackoff and Sleven (1968).
7. Examples of this work are numerous. Some of the ones more frequently mentioned are (Black, 1924), (Bean, 1939) and (Moore, 1914). G. Johnson has referred to these methods as "pencil and paper" projections.

FOOTNOTES (Con't.)

8. For a more detailed chronicle of this sequence of events, see Judge (1968). There were, of course, other types of farm management studies, perhaps more akin to the systems approach, going on simultaneously. However, the thrust of the profession seems to have been in the direction we have identified.

9. In the case of firm studies we find this approach ably described by (Cyert and March, 1963).

10. The former are strictly only associated with stochastic systems (McMillan and Gonzales, 1965).

11. It is important not to confuse these relations with the usual conventions of functional notation. As specified in this context, they are to be thought of in the more general logical sense.

12. We could as well think of observing the system over space, individuals, etc.. The time convention in regard to states is, however, typical and of value in most types of economic systems.

13. For lucid discussion of this state concept as applied to time related problems, see Bellman (1958).

14. In large models involving developing economics this attribute of the systems approach has been applied to considerable advantage (Johnson, et al., 1971).

15. When we observe, as is mentioned later, that the normative concepts involved in many systems models are rather unrefined, the possibility of viewing a system in these terms becomes more obvious.

16. Such examinations may obviously be conducted via sensitivity analysis.

17. In the context of applied modelling situations see (Christ, 1966) for a more detailed discussion of the scientific method.

18. For an illustration of this sort of data minning exercise see (Ramsey and Zarembka, 1971). The authors include an intuitive discussion of the meaning of Classical statistical tests when several alternative functional forms are under examination. For a further exposition of these problems and a discussion of preliminary test and sequential estimators, see Wallace and Asher [1972].

19. This and the subsequent discussion, for the most part, does not consider the actual complexity of selecting among alternative model specifications. 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 context of non-nested hypotheses. Unfortunately, the tests developed by these authors cannot be performed routinely since the form of the test statistic depends crucially on the nature of the hypotheses to be tested.

20. Use of the term verification in this context is somewhat misleading. We employ the terminology only to be consistent with other writings on systems models. That is, the term is used to describe the process of determining the degree to which the model can be confirmed as representing the system.

21. In systems models which contain substantial numbers of dummy shift variables and time counters these internal consistency tests lose much of their value. That is, 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.

22. See the table and related references for more details as to the test statistics associated with these methods.

23. Internal consistency investigations are also employed as a basis for determining whether or not the model is functioning as expected. (Halter, et al., 1970). For purposes of the comments to be made on verification it is assumed that such tests have already been made and that the model is performing as intended.

24. Stability and instability, the speed of convergence from perturbations, values of multipliers, etc., are the types of properties of the model which would be examined.

25. Possibilities for normative verification are discussed by Johnson and Zerby (1972). However, aside from some possibilities of developing weights for criterion functions for decision models (Nijkamp, 1970), the practical feasibility of such approaches seems to be limited. For this reason we have limited the discussion of the problem.

26. The first instance of such a game in Agricultural appears to be one introduced by Eisgruber (1965).

27. The studies in general indicate that games or gaming exercises are productive. However, there is little by way of an economic analysis which would give some guide as to the costs and benefits of games in the various types of teaching and extension activities in which Agricultural Economists engage.

28. In examining this and the remaining Tabular Survey Tables the following should be noted. First, in the decision variable column we report for behavioral and forecasting model applications the variables (endogenous) which refer to actions taken by the behavioral units while for decision model applications we report those variables (exogenous) 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 a bit arbitrary. More specifically, some models in which weak departures from linearity exist are nevertheless classified as linear models. Third, in the sixth column we classify as stochastic those models which are simulated stochastically and not constructed models which incorporate stochastic elements. Fourth, the verification column contains a check mark if more than naive validation procedures (e.g., a graphical comparison of simulated and actual sample values) are employed. Last, for the computer language designation we classify all simulation models for which the computer language is not reported or it was not possible to infer the actual computer language utilized as Fortran.

29. This is reasonably clearly indicated in a series of papers published out of a Great Plains Regional Committee Conference held in 1965 (Great Plains Agricultural Council, 1967). This committee represented one of the first organized attempts to work on growth problems by the profession.

30. It is interesting to note that the Cohen study represents 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 associated slope coefficient equals unity. As subsequently

demonstrated, this procedure in the context of stochastic simulation is incorrect. For further details, see Rausser and Johnson (1972).

31. Computed as the ratio of total realized revenue for all firms divided by total potential revenue for all firms.

32. Increased message costs depressed firm size while random preference orderings reduced the inequality of size among broken firms.

33. A market segment is defined as a group of firms which trade with each other but not with other firms.

34. As the authors put it . . . "Instead of representing an attempt to correct a low grower profit situation, the policy was designed to help keep such a low profit situation from developing" Raulerson and Langham (1970, p. 203).

35. For 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.

36. For further details, see Rausser and Johnson (1972).

37. The principal exception to this statement appearing in Survey Table V is the U.K. food and agricultural model constructed by McFarquhar and Evans (1971).

38. To be more precise, the criteria function employed by these authors is only partially explicit. This is the case since their criterion function was expressed in terms of four independent criteria for which neither weights, satisfactory levels, or orderings were specified. These assignments, the authors suggest, are reserved for the policy maker.

39. In particular, total corn stock accumulation, total government costs, average net farm revenue, and average net farm revenue of participating farms are the response variables.

40. Specifically, it was found . . ."possible to cut cost by 67 percent and reduce surplus accumulation by 46 percent below the lowest corresponding bench mark values of these responses. Similarly average income was raised by about 10 percent. However, only a slight improvement, 3 percent, was achieved in income" Shechter and Heady (1970, p. 47).

41. For a interesting comparison of alternative sectoral models with specific reference to their uses in planning and program design, see Thorbecke (1971). The comparison made by Thorbecke is in more detail than the limited one attempted here.

42. For a more detailed discussion of the possibilities along these lines, see Johnson and Rausser (1972).

43. Each of these studies appear in Water Resources Research. They are Askew, *et al*., [1971], Chow and Kareliotis, [1970], Huggins and Monke, [1968], McMahon and Miller, [1971], Rodriquez-Ituke, *et al*., [1971], and Shih and Dracup, [1969].

44. It should be noted that a reference is made to an earlier publication on this matter.

45. A valuable aspect of this study is the inclusion of an appendix containing a short discourse on the management of a multidisciplinary research project.

46. In a dynamic context, costs depend not only upon the current level production, but also upon cumulative experience.

FOOTNOTES (Con't.)

47. This study also provides some of the components of a soon to be completed Ph.D. dissertation (which incorporates more elements of a complete water resource system). In particular, multiple use sectors, spatial, and alternative sources of water supply are explicitly recognized. This conjunctive water resource systems model is constructed for the San Luis Obispo - Santa Barbara region in California. The decision variables which are examined include: public subsidies to water desalting plants, investment sequencing and timing of alternative water supply projects (e.g., surface water transport facilities, desalting plants, groundwater supply developments), and temporal spatial, as well as sector use, water pricing and quantity allocations.

48. For the details, see Dudley, et al., [1971, 1971 a].

49. Improving to the point that the costs from further improvements in the system representation are in excess of the benefits from the refinements in its use.

50. The foundations for their approach to this problem may be found in Pratt, et al., [1965] and Schlaifer [1959].

51. For a recent application of these methods to a predecision process in farm planning, see Lee (1971).