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AN EXPLORATORY STUDY OF SELECTED ASPECTS OF THE PUBLIC SCHOOL SYSTEM IN MICHIGAN EMPLOYING SYSTEM SIMULATION

By

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ABSTRACT

AN EXPLORATORY STUDY OF SELECTED ASPECTS
OF THE PUBLIC SCHOOL SYSTEM IN MICHIGAN
EMPLOYING SYSTEM SIMULATION

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William Harold Holloway

This study was both developmental and analytical. A computer simulation model was developed to represent two components of the public school system in Michigan. The two components were: the student population sector and the teacher population sector. The basic assumption was that the number of public school students for any given year represent a primary drive of the system. Therefore, a dynamic supply-demand function should exist that would permit prediction of the number of professional staff needed to provide services to the public school students in Michigan in any given year. Specifically, the question was asked whether such a simulation model be developed; and, given that development was possible would the model be efficacious? That is, could the simulation vehicle generate predicted levels of needed professional staff which would be more accurate than predictions which

could be obtained by conventional forecasting techniques, such as the method of moving averages (two year) and exponential smoothing ($\alpha = .8$).

Data related to student and teacher populations (SPOP and TPOP respectively) were aggregated at the state level and also collected for factors and parameters within each component which contributed to variance of the two status variables SPOP (t) and TPOP (t). System identification was completed by formulation of operating characteristics for each component and specification of the hypothesized supply-demand relationship detailing component interaction. The mathematical model was translated into a computer program employing Fortran IV and written for the Michigan State University, CDC-6500 system. This completed the development phase of a linear, dynamic, discrete, and deterministic simulation model.

The analytical phase of the study required consideration of model verification, model validation, and completion of planned experiments. Thiel's U statistic was employed to guide model verification as an estimate of the congruence of simulator generated time series with the corresponding real world time series for the primary endogenous variable TPOP (t).

Model validation required a presentation of the structural elements of the model in relation to corresponding elements of the real world system of interest. Questions from a list which had been formulated prior to model identification were subsequently answered. In addition, a rationale was provided which attempted to explain why the model had been conceptualized in the present form.

Two experiments were conducted after model verification and validation was completed. Both experiments compared the accuracy of forecasts achieved by simulation, moving averages, and exponential smoothing. The first experiment concerned forecasts required for short-range (year to year) planning and the second experiment concerned forecasts for long-range (ten year) planning. Each experiment employed a fixed effects, analysis of variance model. The independent variable was treatments (method of forecasting) and the dependent measure was the difference between attained predictions and actual values of TPOP (t). A ten year period of time (N = 10, 1959-1968) was designated as the period for comparison. All statistical tests employed an alpha (α) level of .05.

In the first experiment the attained value of the mean square ratio for types of forecasting methods (2.79) was not significant at the .05 level and the null hypothesis of equal accuracy in forecasting was retained. In the second experiment the attained value of the mean square ratio 9.85 for types of forecasting methods was significant at the .05 level. Follow-up tests were conducted using post hoc procedures. Of the three pair-wise comparisons, two were found to be significant. That is, both simulation

and exponential smoothing forecasts were found to be significantly more accurate than moving averages. There was no significant difference between simulation forecasts and predictions achieved by exponential smoothing. In both experiments, it was observed that the mean difference for simulation forecasts was more accurate than the mean difference forecast by either of the aforementioned methods.

It was concluded that a linear, discrete, dynamic, and deterministic simulation model could be developed; and, the model would generate time series data which were congruent with time series data for corresponding variables of the real world system of interest. Where short-range planning forecasts are desired any one of the three methods will provide equally accurate predictions. When long-range forecasts are desired, predictions obtained by simulation or exponential smoothing methods will be significantly more accurate than moving average predictions. Implications and suggested areas for future research were discussed.

DEDICATION

To those who can only wait with infinite patience and understanding: my wife and children. May they find some measure of satisfaction in the knowledge that this goal could not have been realized without their support.

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The writer wishes to express his appreciation for the able and ready assistance that was extended to him in so many unrecorded, yet not unnoticed ways, by the faculty and staff of the College of Education.

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CHAPTER I

INTRODUCTION

The investigator's experience in education both as teacher and administrator has evidenced an enduring interest in applied quantitative methodology and an increasing interest in the potential value of the computer to the practice of administration.

During this period of time it has been observed that educational systems have continued to grow in their complexity. School staffs have been expanded to include heretofore unknown personnel. Roles have been redefined to reflect changes in patterns of responsibility and increasing specialization. New communications systems have been implemented to accommodate the information needs of independently and interdependently functioning subsystems. Increasing attention has been focused on intrasystem linkage and interaction as well as on the relationship of the district with ancillary and supra-systems. The expansion of traditional boundaries has resulted in a loss of autonomy and district independence giving way to greater inter-system dependence.

The growing complexity of the educational enterprise has predicated change in the character of administration. Entirely new concepts of control have evolved such as PERT (Program Evaluation and Review Technique), PPBS (Planning, Programming, and Budgeting System), and CMI (Computer Managed Instruction). Administrators are increasingly turning to the computer for storage, retrieval, and analysis of information about the status and direction of the system giving way to concepts of MIS (Management Information System) and MBO (Management By Objectives). Such changes have frequently resulted in adoption of planning and evaluation programs and an accompanying need for enlightened understanding of the total enterprise. Comprehensive theory and utilization of advanced technology appear to have considerable promise in this regard.

The work of Koenig, et al. (1968), Van Dusen (1969), and DeLeeuw and Gramlich (1968) represents recent efforts to explore analytical tools which hold promise for a wholistic approach to the exploration of behavior in systems. The inherent value of such techniques to researchers resides in the extended capability to encompass a multitude of system variables. McNamara (1971, p. 434) notes, the primary limitation of such approaches is the necessity for a considerable body of information about the system. However, Holland and Gillespie (1963, p. 23) had previously advocated, " . . . rather than wait for adequate data before doing a simulation, it would be useful to make a simulation study before going too far with statistical research so that the latter could be focused more sharply on the data that matter most."

At present, there is a need for further exploration of educational systems as wholistic entities. Further, in many cases (for example, the state public school system in Michigan) an adequate base for wholistic analysis already exists since information is regularly and uniformly collected from all school districts in the state. The availability of the data facilitates the problem of considering the system with a wholistic perspective. However, the extensiveness of the data base produces another associated problem. How can the multitude of data that emanates from the system be organized, assimilated, analyzed, and synthesized to produce not just data but information which focuses on the functional integration of parts--in short, preservation of the wholistic perspective?

The writer elected to pursue simulation research because of long standing interests and past experiences in education which suggested that a wholistic approach to organizational analysis is more powerful than a particularistic approach. A problem which seems ripe for wholistic analysis is the relationship between student population levels (demand) and professional staff (the supply). Recent experience indicates that professionals have been trained with little regard for the demand posed by the market. There is an obvious need to balance the supply and demand. However, even more crucial is the need to understand the dynamics of supply and demand relationships.

Past investigations (Costa, 1970; Michigan Education Association, 1971) have been particularistic and have explored various strategies for predicting supply-demand relationships including the method of moving averages and exponential smoothing. However, it is believed the particularistic studies which tend to ignore the dynamics of component interaction and conventional forecasting strategies many of which are no more than mechanistic algorithms fail to achieve the predictive potential that may be possible through the wholistic approach of system simulation.

Statement of the Problem

The basic problem to be studied was methodological and heuristic in nature. That is, could a simulation model be developed and if so, would the model be efficacious? The investigator attempted to develop a simulation of the public elementary and secondary school system in the State of Michigan. Attention was focused on student population and professional staff levels as two major components of that system. Given that such a model could be achieved, the dynamics of the system would be explored to determine the predictive potential of the model. The predictions of needed professional staff generated by the simulator were then to be compared against predictions achievable by conventional forecasting techniques, such as the method of moving averages and exponential smoothing.

Couched in these terms the problem encompassed two major sub-problems:

1. Development: Can a valid simulation model be developed which would represent the dynamics of two major components of the public elementary and secondary schools in the State of Michigan?

2. Exploration: Can the simulation model provide more accurate predictions for planning purposes than conventional forecasting techniques?

Need for the Study

The nature of the problem selected for study predicated a two-fold discussion of needs. First, development of a computer simulation model addresses the methodological need for simulation research in education. Second, application of the model addresses the need to obtain more valid planning information regarding the dynamics of supply and demand for certificated professional teachers in the State of Michigan. The discussion of needs is presented in that order.

Need for Simulation Research

The behavioral sciences unlike the physical sciences are disadvantaged by the lack of comprehensive theories, tools of analysis, and precise measurement instruments. However, the scientific task of theory development in the behavioral sciences still moves forward employing the available instruments regardless of their incomplete state. It seems reasonable that a proportion of research effort should be directed toward exploration, development, and perfection of research tools that indicate some measure of promise. In this regard, Elton and Rosenhead (1971, p. 139) write with reference to the behavioral sciences in general:

> An area which needs particular attention is that of the testing and validation of simulation models. The present position (it works if management says it works) is less than satisfactory, and there is need for more objective test procedures. More experience is needed in the development of modular simulations--where particular formulations can be unplugged and others substituted with a minimum of fuss.

Other authors (Van Dusen, 1969; Mauch, 1962) address the need for exploration of such tools as linear programming, queueing theory, systems analysis, and simulation in the field of education. McNamara (1971, p. 419) comments:

> Management science models which express the organizational environment and its dynamics in mathematical relationships have been applied in the fields of business management, military operations research, public welfare and regional planning. Although the value of such models has been demonstrated in the

areas listed above, educational administrators and planning specialists appear to be making little use of these scientific approaches.

The analysis of systems from a "wholistic" orientation is contrary to current research methodology which advocates limited arrays of independent and dependent variables. In this regard, Bertalanffy (1968, p. 31) suggests: "It is necessary to study not only parts and processes in isolation, but also to solve the decisive problems found in the organization and order unifying them, resulting from dynamic interaction of parts, and making the behavior of parts different when studied in isolation or within the whole." Wholistic studies require techniques capable of encompassing and manipulating a multitude of variables. At present, such techniques are not an integral part of the array of educational research tools. Smith (1968, pp. 326-26) concluded from his study that using all the variables, " . . . would have required 10^{70} outcomes to provide a model encompassing all possible events. This figure approaches the estimated number of atoms in the known universe 10^{76} . . ."

Research approaches dealing with organizations are frequently limited or prohibited by the necessity to respect the organization's right to continue uninterrupted, such as, the problem of experimental control. Simulation, as a tool of analysis is an alternative which permits organizational research without interruption. At the same time, the need for experimental control is resolved. Mauch (1962, p. 159) touches upon this advantage of simulation studies as further justification for the employment and exploration of simulation as an important alternative.

Need for Planning

The need for planning in educational systems may be interpreted as the need to devise or identify new or revised procedures through which explicit systemic goals may be accomplished (Webster, 7th ed.). Planning is further related to policy in the sense that policy is a legitimized procedure or course of action. The logic suggests that planning ought to precede procedure specification and formal policy action, though this may not always be the case in practice.

Heald and Moore (1968, p. 122) clearly indicate that leadership is one of three major responsibilities which define the role of the school administrator. Lipham (NSSE yrbk., 1964, p. 122) takes the position that leadership is the initiation of a new structure or procedure for accomplishing or changing systemic goals or objectives. Clearly then, the school administrator is responsible for leadership acts, leadership entails the initiation of new or modification of existing procedures and at least a portion of such activity may be broadly interpreted as planning. Thus, the extent to which there is need for revised or new procedures there is need for planning. It is contended that examination of the need for planning may be accomplished indirectly through examination of the need for new or revised procedures.

The problem at hand concerns the nature of dynamic relationships between and within two of the four essential components (teachers and students) of public school systems as identified by Heald and Moore (1968, p. 10). To what extent is there evidence of the need for new or revised procedure in relation to the components of interest?

In a paper reviewing teacher supply and demand in the State of Michigan, the State Department of Education (1971, p. 1) notes that:

> For more than a quarter of a century, Michigan and the nation have had a shortage of teachers for the elementary and secondary schools. The dimensions of the problem have varied but never has the problem been of less than major proportions.

By inference, it may be reasoned that a primary objective of the teaching profession and of teacher training institutions under such circumstances was to reduce or eliminate the supply disparity (under-production). It may additionally be inferred that at least one alternative to such an objective may have required some change in procedure and policy in order to accomplish the objective since the system as defined was not keeping pace with demand. The same reference (MSDE, 1971, p. 1) continues:

"Within the past two years (1969 and 1970) the shortage has been alleviated; June, 1970 graduates receiving teachers certificates frequently found difficulty in obtaining positions."

Irrespective of what factors were influential in this change, dynamic equilibrium of the system was momentarily restored as supply reached the level of demand. However, the duration of the resultant state of equilibrium was brief as other social forces (increasing salaries, etc.) converged to attenuate the precarious balance.

Various studies (MSDE, 1971; NEA, 1970; USOE, 1970) provide current estimates for Michigan that indicate the overproduction of teachers for 1971-72 may reach as high as 16,000. Long range estimates, on the other hand indicate overproduction will gradually increase to 19,000 by 1979-80. The mandate for some type of change in procedure is clear as are some of the alternatives such as control system design. Johnson, et al. (1967, p. 86) write: " . . . the objective of control system design, therefore, is to determine the relevant characteristics which, when con-rolled, maintain the function of the system within allowable variations."

Given the assumption that variation of the system within tolerable thresholds is desirable, several control alternatives can be formulated. Evidence might indicate a reduction in pupil-teacher ratio as a solution to the imbalance. In essence, a reallocation of resources. Or, financial and other factors may dictate that the production flow be adjusted to produce certificated professionals according to some pre-determined replacement need and thereafter to maintain the status quo. This action would constitute a re-ordering of policy and procedure which would initiate repercussions in ancillary components.

In summary, it seems clear there is a need for the development and testing of vehicles which enable explanation and exploration of system dynamics. Given that such a model can be developed and validated there is further need for the testing of alternative policy strategies as one approach to the generation of planning information which is in part derived from the evaluation of alternative strategies.

Purpose of the Study

It was the purpose of this study to examine the relationships between student population levels and demand for professional staff in the public school system in Michigan. It was expected that boundaries of the sub-systems would be established, important system variables would be identified, a determination of exogenous and endogenous variables could be accomplished, and the functional relationships between such variables could be established prior to the development of a computer simulation program. It was believed that further refinement of the functioning system would provide a basis for the generation of predictions which would add credence to the analytical potential of simulation in general, and this model in particular.

Given that the model could be developed, a test was designed to compare simulated prediction results against those achievable by other forecasting techniques, such as, the method of moving averages and exponential smoothing. The purposes of the test would be to acquire additional credibility for the model and its performance in relation to short and long range planning needs. If the test were successfully passed, it would then be possible to examine the effects of various policy alternatives related to the current oversupply of teachers at enhanced levels of confidence. Such ongoing experimentation would facilitate production of planning information necessary to educational administrators as they contemplate new or revised procedures and policies for the system.

Directly related to the stated purpose of this study are the following objectives:

1. Development of a simulation model.
2. Development of a functional computer program which embodies the simulation model.
3. Validation of the model.

4. Verification of the model.

5. The completion of two related experiments with the simulation vehicle.

Definition of Terms

The following terms are relevant to this study and are defined as follows:

Component.--An identifiable sub-system of the system of interest. In this study two components or sectors are considered; they are the student population sector and the professional staff sector.

Deterministic.--Response patterns of simulator generated data which are fixed as opposed to varying.

Discrete.--Models which incorporate time as a series of distinct units as opposed to a continuous time series. All simulation models can be considered discrete since continuous time sequences cannot be operationalized only approximated by making the incremental unit of time extremely small.

Dynamic.--A system in which the response is dependent upon past values of the input is said to be dynamic and to have memory. Thus, time becomes an important parameter in the system.

Model.--A mathematical description of the system of interest. In this sense a "symbolic" model (Churchman and Ratoosh, 1959, p. 158) where symbols designate properties of the system of interest.

Parameter.--A parameter is a variable whose value may be assigned by the investigator to reflect various conditions in the system. A parameter is not necessarily constant.

Professional Staff.--Any individual who is permitted by virtue of accepted credentials to conduct instruction in the public elementary and secondary schools of Michigan.

Simulation.--A representation of some aspect of reality. Computer simulation implies the representation will be translated to a computer program medium.

Student.--Any person, who by virtue of age, is admissable to the public elementary and secondary schools of Michigan.

System.--A collection of identifiable, interacting parts deliberately constructed to achieve specific goals. In this study the system of interest is the public schools in Michigan.

Forecasting Techniques.--Methods or strategies for obtaining future values of variables of interest. In this study, only the method of moving averages (two year) and exponential smoothing (α = .8) will be considered.

Limitations of the Study

In view of the amount of time and resources required for most simulation studies, it seemed advisable to reduce the scope of this effort to manageable proportions. Therefore, only two components of the public school system in Michigan have been included. Conclusions derived from the study should not be generalized beyond the limits of these sectors nor to school systems other than Michigan.

The test of the predictive ability of the model could not consider all possible forecasting techniques. Therefore, the techniques selected were chosen on the basis of ease of employment, general utility and recognition by others in the field. The modifications of these methods (for the purposes of the second experiment) were constructed on the basis of the expected course of action by those attempting to employ moving averages or expotential smoothing given the situation calling for long range planning information, that is, ten year periods.

Assumptions

The assumption was made that student population levels in any given year and within prescribed age limits described a major impetus for system response. It is believed that sufficient legislative mandate, prior studies, and empirical evidence exist to support such an assumption. At the same time, however, it is recognized that a computer simulation model constructed on the basis of a different postulate could have resulted in a different perspective of the system and entirely different conclusions.

Finally, it was necessary to assume the system of interest to be block recursive. That is, it was assumed that interaction among other components of the system of interest, such as administrators and Boards of Education could be considered negligible.

The review of the literature which follows deals with important areas of simulation research. First, general systems theory and the current state of theory development insofar as the organization is conceptualized as a system. Second, the much lesser developed field of computer technology and in particular computer simulation. The third area concerns rational planning and the need for improved methods of prediction.

CHAPTER II

REVIEW OF RELATED LITERATURE

The review of literature undergirding this study concerned three topical areas. First, consideration of the organization as system reviews important concepts and the current state of theory development in this field. It is believed that an awareness of organizations as systems is important as a prerequisite to the rationale for mathematical analysis and system simulation. Second, the review encompasses technological aspects of computer simulation concluding with a review of the controversial issue of statistical analysis. Third, the review deals with planning as an integral part of the role of management. Planning has previously been defined as the development of new or modified procedures for goal achievement. In this sense, planning is predicated upon the acquisition of information concerning dynamic aspects of the system and the ability of managers to predict future behavior.

The Organization as System

Numerous authors (Bertalanffy, 1960; Griffiths, 1959; Johnson, *et al.*, 1967; and Parsons, 1951) have explored the utility of systems thinking as a conceptual framework for organizational theory. Each in his own right has contributed substantially to the further elaboration of such a theory, yet the work represents only a beginning. In view of the absence of a comprehensive theory from which to depart, the best strategy would be to employ a systems approach to the task at hand, taking full advantage of accepted concepts from General System Theory (GST) and drawing appropriate parallels to a theory of organization where these exist. Johnson, *et al.* (1967, p. 69) state:

> Thus modern organization theory, as it has evolved, inevitably merges into concepts of general systems theories. Scientific investigation and research findings using general systems theory as a frame of reference can provide important understanding of the most complex of manmade systems--his large scale social organizations.

This section of the review deals with the organization as system. Three sub-topics will be considered: general systems theory, concepts and definitions in GST, and finally the organizational system.

General Systems Theory

While definitions of the term system have been advanced by many authors in the field, there appears to be emerging agreement upon at least two levels of definition. The more general, advocated by Bertalanffy (1968, p. 38) as, " . . . sets of elements standing in interaction . . .," speaks to every possible system. Other authors support the more particularistic viewpoint such as that advanced by Heald and Moore (1968, p. viii), " . . . a system is a series of essential components whose functions are coordinated for the purpose of achieving the goals of the organismic whole." The term organization varies as a function of the particular theory, but may be approached in terms of system. Thus, Cooper and McGillem (1968) and Etzioni (1964) provide the basis for the following definition which will be used throughout the study. An organization is a planned system of interacting components deliberately constituted and reconstituted to achieve desired goals.

It should be stressed that the above definition of organization requires that social organizations be considered only one category or subset of all possible systems. Boulding (1967, pp. 10-13) has proposed an ordering of systems according to their general characteristics or lack of them. Specific levels in the ordering scheme are as follows:

1. <u>Static structure systems</u>--atoms, the planets.
2. <u>Dynamic systems</u>--the level of clockworks.
3. <u>Cybernetic systems</u>--the level of feedback.
4. <u>Life-maintenance systems</u>--the level of open systems, distinguished by life as opposed to not life, the cell.
5. <u>Genetic-societal systems</u>--the level of division of labor, blueprinted growth, typified by the plant.

6. The animal system--a level characterized by increased mobility, teleological behavior, and self-awareness.
7. The human system--a level which possesses all of the characteristics of the previous six and in addition, self-awareness, and self-consciousness, i.e., man not only knows but he knows that he knows.
8. Social systems--the level of organization.
9. Transcendental systems--the level of systems of systems.

The ordering scheme proposed by Boulding (1967) has been devised so that each ensuing system is a more advanced and complex level incorporating the characteristics of all foregoing levels. Bertalanffy (1968, p. 32) thus concludes that organizations as systems may be expected to display such characteristics as distinct physiologies, metastasis, homeostasis, and self-maintenance. The author further suggests:

> It seems legitimate to ask for a theory, not of systems of a more or less special kind, but of universal principles applying to systems in general. In this way, we postulate a new discipline called General Systems Theory. Its subject matter is the formulation and derivation of those principles which are valid for systems in general.

General systems theory is concerned with developing a systematic, theoretical framework for describing general relationships of the empirical world. A broad spectrum of potential achievements for such a framework is evident, Existing simularities in the theoretical construction of various disciplines can be pointed out. Models can be developed which are applicable to many systems, whether physical, biological, behavioral or social. An ultimate but distinct goal will be a framework, transcendental theory (a system of systems of systems) which will tie all disciplines together in a meaningful relationship. In the words of Boulding (1967, p. 6), " . . . this is the quest of GST."

Johnson, et al. (1967, pp. 9-10) summarizes the state-of-the-art in theory development using Boulding's ordering scheme as a frame of reference:

> Dynamic clockwork systems, where prediction is a strong element, are evident in the classical natural sciences such as physics and astronomy; yet even here there are important gaps. Adequate theoretical models are not apparent at higher levels. However, in recent years closed-loop cybernetics, or "thermostadt" systems have received increasing attention. At the same time, work is progressing on open loop systems with self-maintaining structures and reproduction facilities. Beyond the fourth level we hardly have a beginning of theory, and yet system description via computer models may foster progress even at these levels in the complex of general systems theory.

Bertalanffy (1968, p. 196) criticises the efforts of "Functionalist theories" as represented by the work of Parsons, Merton, and others.

> The main critique of functionalism particularly in Parson's version, is that it overemphasizes maintenance, equilibrium, adjustment, homeostasis, stable institutional structures, and so on, with the result that history, process, sociocultural change, inner-directed development, etc., are underplayed and, at most, appear as "deviants" with a negative value connotation. The theory therefore appears to be one of conservatism and conformism, defending the "system" (or the megamachine of present society, to use Mumford's term) as is, conceptually neglecting and hence obstructing social change. Obviously, general system theory in the form here presented is free of this objection as it incorporates equally maintenance and change, preservation of system and internal

conflict; it may therefore be apt to serve as logical skeleton for improved sociological theory.

Basic Concepts and Associated Definitions

A number of basic concepts have become recognized by authorities in the field. The basic concepts are defined by varying authors and presented as follows:

1. Boundary: Bertalanffy (1968, p. 215) proposes:

> Any system as an entity which can be investigated in its own right must have boundaries, either spatial or dynamic. Strictly speaking, spatial boundaries exist only in naive observation, and all boundaries are ultimately dynamic. One cannot exactly draw the boundaries of an atom (with valences sticking out, as it were, to attract other atoms), of a stone (an aggregate of molecules and atoms which mostly consist of empty space, with particles in planetary distances), or of an organism (continually exchanging matter with the environment).

The boundary concept suggests that some determination may be made to distinguish that which is considered an inherent part of the system of interest (the organization) and that which is not (the environment). In this respect, it is not unlike the concept of "set" though eminently more difficult to determine particularly where the reference is to dynamic systems. Pheiffer (1968, pp. 21-32) in discussing the procedures of a systems approach concludes that identification of the boundaries of a problem is a prerequisite to problem definition.

The concept of boundary leads quite naturally to the related concepts of open and closed systems.

2. Open and Closed Systems: As all systems have boundaries, the open-closed continuum concept provides a relative description of boundary permeability. Parsons (1951) speaks of the term "boundary exchange" in describing the exchange between two systems or between a system and its environment. Johnson, et al. (1967, p. 11) contributes the following in the same regard:

> An important aspect of general system theory is the distinction between closed and open systems. An example of an open system is a living organism which is not a conglomeration of separate elements but a definite system, possessing organization and wholeness. An organism is an open system which maintains a constant state while the matter and energy which enter it keep changing (so-called "dynamic equilibrium").

In reality, the completely open or completely closed system does not exist, since the one would preclude the existance of any boundary and the other would admit to an impermeable boundary. Thus, systems are often described as relatively open or relatively closed which relates to the degree of freedom associated with boundary exchange.

3. Equilibrium: An important concept in GST is that of equilibrium which relates to balance in the system. Static equilibrium, for example, is the balance point reached in chemical reactions where two or more substances react and arrive at a final, predictable state. Dynamic equilibrium, however, is not so easily formulated. Bertalanffy (1968, p. 132) writes,

> We are not in a position to define such equilibrium state in complicated organic processes, but we can easily see that such a conception is, in principle, inadequate. For, apart from certain individual processes, living systems are not closed systems in true equilibrium but open systems in a steady state.

4. Feedback: Carzo and Yanouzas (1967, pp. 364-65) define feedback as information received describing existing conditions. In this respect, the feedback may originate with the environment, so-called external feedback, dealing with the performance of the system. Feedback may also be internal relating to the performance of internal components or elements.

5. Equifinality: Important to the theory of open systems is the concept of equifinality about which Bertalanffy (1968, p. 132) says,

> An aspect very characteristic of the dynamic order in organismic processes can be termed as equifinality. Processes occurring in machine-like structures follow a fixed pathway. Therefore, the final state will be changed if the initial conditions or the course of processes is altered. In contrast, the same final state, the same "goal," may be reached from different initial conditions and in different pathways in organismic processes.

Humans, in a biological sense, achieve similar stages of development given widely differing inputs of diet (physical) and environments (social). Another example, is that of school districts which achieve similar goals given widely differing teaching staffs, financial resources, physical facilities, and student populations.

6. Stress: The concept of stress in open systems embodies aspects of force, drive, need, disparity and in the Parsonian model is specifically identified as "tension management." Stress is conceived as an imbalance between two entities such as supply and demand or between two individuals in power relations. In modern organizational theory the concept of stress is increasingly becoming accepted as a state that is not necessarily detrimental to the system. That is, perhaps a certain amount of stress is necessary to the functioning of the system. This is in contrast to the former ideology that any evidence of stress or strain in relations was indicative of dysfunction in the system.

7. Input-Output: In closed systems, there is an absence of boundary exchange. In open systems, there is exchange between ancillary systems, such as, system to system or between the system and the supra-system (environment). Boundary exchange may be beneficial or detrimental to the system and its state of equilibrium. That is, in a biological sense an organism may "input" a toxic substance or a nutritious one. Similarly, output in an organizational sense may take the form of well trained professionals or it may take the form of heavy volumes of unwanted fumes such as automotive or industrial exhaust.

8. Process: In open systems, process relates inputs to outputs and tends toward progressive segregation, that is, increasing autonomy of parts and development of new structure. In closed systems, process tends toward systemic entropy, that is, tendency toward disorder. Organizations as open systems continually devise and implement new structure while chemical substances in a relatively closed system tend toward a heterogenous state.

The concept of "process" in the public school systems is crucial to this study as is the concept of "stress" upon which the study is founded. Within the public school system there are numerous interactions within and between the components of the system for which process ought to provide some explanation. For example, students enter the system and constitute a demand for service. Provisions of appropriate service requires allocation of the resources of the system. Primary resources generally take the form of physical facilities, professional and non-professional staff, and materials and supplies. Since the allocation of systemic resources is not instantaneous, advance information (predictions) of the expected level of demand (stress) is periodically sought as are estimates of the expected level of resources (supply).

Stress occurs in different forms (goals to be served, power imbalances, clients to be served). Further, it is possible to visualize distinct sub-processes of the overall educational process (resource acquisition and distribution, non-professional staff service, program evaluation). This study assumes that the number of students to be served is a primary demand on the system for professional staff services. The process to be identified and modeled concerns the interactions that occur within and between the student population and professional staff components as the supply-demand function moves toward a state of equilibrium.

Other concepts such as sensitivity, stability, and progressive segregation are discussed in the literature (see for example, Johnson, et al., 1967, pp. 72-73) but complete closure is not necessary for the purposes of this study.

The foregoing part of the review identified basic concepts and stated rather commonly accepted interpretations of these concepts. The present level of theory development as regards GST is only now in its infancy. That is, the work at present is concerned with concept identification and construct development.

Organizational Systems

Current research in organization theory recognizes at least three models, the rational, the natural systems, and the analytical (Johnson, et al., 1967, p. 44).

1. Rational Model: Phiffner and Sherwood (1960, p. 30) define the rational model for organization as: " . . . the pattern of ways in which large numbers of people, too many to have intimate face-to-face contact with all others, and engaged in a complexity of tasks, relate themselves to each other in the concious, systematic establishment and accomplishment of mutually agreed purposes."

2. Natural Systems Model: Much of the current literature utilizes the natural systems model as a basis for analysis. March and Simon (1958, p. 4) define organization as follows:

> Organizations are assemblages of interacting human beings and they are the largest assemblages in our society that have anything resembling a central coordinative system . . . the high specificity of structure and coordination within organizations--as contrasted with the diffuse and variable relations among individuals--marks off the individual organization as a sociological unit comparable in significance to the individual organism in biology.

3. The Analytic Model: The analytic system model for organization theory is described by Andrew (1965, p. 198):

> The general analytic model presents an organization as an adaptive system (goal directed) with a set of interdependent variables, adjusting to each other upon stimulation of one or more of them from system parameters. The plastic nature of adaptive systems is characterized essentially as the ability of those systems to arrive at goals under a variety of different conditions. The concept of an adaptive system, thus defined, permits explanations of the nature of both persistence and change in an organization and further of the nature of interrelationships between subparts of the total organization.

Thus, there are at least three recognized orientations to organizations as systems. The rational model could well lead to a process representation which would depict system process as the relationship of input to output and where output was the result of rationally determined systemic goals. Such a representation could easily differ from a model developed from a natural system or analytical orientation. More remains to be said about modeling. However, the remainder of the discussion is presented in the ensuing section which deals with simulation.

Carzo and Yanouzas (1967, p. 236) integrate concepts and definitions to present a functional picture of the organization as system.

> In essence, society (the environment) is a suprasystem and has a mutually dependent relation to the formal organization (the system). As a basis for design, we treat the formal organization as a system of interconnected components performing processes on flows of matter, energy, and information. In this context, the formal organization transforms matter, energy, and information into different states or output values. These values are the end product of the flows; they comprise the objectives or desired performance of the system, and through design decision makers are placed in a position to regulate these flows. By regulating these flows, they are supposed to produce the values agreed upon by participants, that is, meet the organizational objectives.

The authors clearly posit the concept of regulation or control as being necessary if organizations are to serve systemic goals and hence society. Johnson, et al. (1967, p. 16) suggests that in fact the functions of management are fourfold:

> Although the management process has been described in numerous ways, four basic functions have received general acceptance--planning, controlling, organizing, and communicating. They can be defined in terms of systems concepts as follows:
> 1. Planning--selecting the organizational objectives and the policies, programs, procedures, and methods of achieving them.
> 2. Organizing--to coordinate people and resources into a system so that the activities they perform lead to the accomplishment of system goals.
> 3. Controlling--assuring that the various subsystems are performing in conformance to the plans. The measurement and correction of activity of the subsystems to assure the accomplishment of the overall plan.
> 4. Communication--transfer of information among decision centers in the various subsystems throughout the organization and the interchange of information with the environmental forces.

The planning function has particular significance in this study and is treated separately as part three of this review.

In summary, GST is a viable, theoretical framework for consideration of the organization as system. The state of theory development in GST has progressed to the identification of an increasing number of concepts and definitions from which relationships are evolving. Griffiths (1959, p. 70) concludes, "Theory builders are struggling with problems of concept development, theory form, lack of testable hypotheses, and lack of precision." While this may no longer be true of some theories (application of the Getzels-Guba model, for instance) it remains true of the development of GST in the field of educational administration.

Aspects of Computer Simulation

In the sense that simulation is interpreted as representation, the act of simulating could be attributed a history as old as man himself. Simulation as representation of certain aspects of reality may abbreviate the historical sequence to some degree, but is still open to considerable interpretation. Computer simulation, however, is a manageable subset of all simulations which is both tractable and more relevant to this review.

Historical Aspects

Two bibliographies were identified (Werner and Werner, 1969; and Dutton and Starbuck, 1971) which provide an important basis for review. The Werner and Werner (1969) publication reviewed simulations other than computer, such as, role playing or "people simulations" categorized by type. Dutton and Starbuck (1971) examined only computer simulation works classified by an ordering scheme related to both nature and substance of the study.

Dutton and Starbuck (1971, p. 9) for example, reviewed some 12,000 articles and concluded that 1,921 of these were relevant to the topic of computer simulation, had been published prior to 1969, and estimated that these represented about three-fourths of all available published works on computer simulation.

The majority of computer simulation studies are not related to the field of educational administration nor, for that matter, to education; however, there is evidence of early works and a growing incidence of increasing attention to educationally oriented simulation studies. Cruickshank (1969, p. 191) cites the work of the University Council on Educational Administrators (UCEA) in development of the "Whitman Elementary School" simulation in the late 1950's as an early effort. Work of more recent vintage is reviewed by Hallworth (1969, p. 62) who refers to the Gullahorn simulation of social interaction (1964) and the work by Cogswell and Loughary (1967) who attempted to simulate a school counselor.

Attempts to define simulation have been made by numerous authors (Guetzkow, 1963; Elton, et al., 1971; Naylor, et al., 1967; and Schechter, 1971) among others. The latter three tend to include references to the operating model, for example, (Elton, et al., 1971, p. 118) they suggest, " . . . a method of making deductions from a mathematical model of a system." However, for outright simplicity and efficacity the definition suggested by Guetzkow (1963, p. 25) is both parsimonious and functional. That is, " . . . simulation is an operating representation of central features of reality." Inclusion of the term "operating" performs a gestalt function which distinguishes simulation from inanimate forms of representation and permits schemes of classification which focus on the manner of operation as opposed to the nature of model construction.

Thus, computer simulation speaks to the manner in which the model is operationalized. Further delineation may then be achieved by considering subsets related to the nature of the model. Where concern is focused on computer simulation of mathematical models, Cooper and McGillem (1967, pp. 11-14) provide an important schema accompanied by appropriate explanation.

Value and Objective Aspects

The importance of simulation research in general, may be inferred from a review of the associated values which have been previously identified. Naylor, et al. (1968, pp. 8-9) provides an inclusive list of such values which have been collapsed to provide the following:

1. Simulation makes it possible to experiment with complex, internal interactions (Multi-variate value).
2. Allowance for changes in the model makes it possible to study informational, organizational, and environmental changes (Decision-making value).
3. Simulation develops a greater awareness of the system and the means of improving it (Design value).
4. Simulation provides a pedagogical device for teaching basic skills in theoretical analysis, statistical analysis, and decision-making (Training value).
5. Simulation yields insight into which variables of a system are important (Analytic value).
6. Simulation can serve as a "preservice test" to try out new policies and decision rules as it permits study of dynamic systems in real time, compressed time, or expanded time (Planning value).

A number of authors (Beck and Monroe, 1969; Cunningham, 1966; Cruickshank, 1969; Entwisle and Huggins, 1967; and Rice, 1964) review the specific values of simulation in training. Wynn (1964, pp. 171-73) however, provides a summary of what other authors have found regarding specific values of simulation in training.

> First, the evident face validity of the situation stimulates interest and motivation in learning and encourages the subject to behave as he might in reality. Second, the written record of performance results in the accumulation of normative data and permits clinical examination and comparison of "on-the-job" behavior in identical situations. Third, simulation permits the learner to profit from mistakes that might be disastrous on the job. Fourth, the instructor in the simulated situation can provide the subject with concepts, research evidence, models, or other information which he can't always send in during the actual game. Fifth, simulation provides an opportunity to see the whole picture, to view each problem in broad context. Sixth, simulation permits a degree of introspection rarely provided on the real job.

Rabow (1969, p. 41) speaks to the multi-variate capability of system simulation.

> It seems that the greatest difficulties in understanding social phenomena are due to both the large amount and variety of factors and occurrences which contribute to social phenomena. Accordingly, both conceptual means and tools must be devised to deal with such a mass of data.

The author advocates that simulation is one such tool that now is in need of further exploration since for the present the potential of computer simulation as a tool of analysis has been sufficiently demonstrated.

Of particular concern to this study however, are values associated with rational planning and decision making. Johnson, <u>et al</u> (1967, pp. 183-84) identify at least two such values.

> First of all, since those persons involved in making decisions in the operation as a whole must verbalize their decision-making process to the researcher, they cannot avoid becoming better acquainted with their

> own operation. The explicitness with which the activities and decisions must be set forth for a simulation model forces those involved to define their own functions clearly. Often this activity in itself can result in benefits . . .

The author continues to fully elaborate the second value as follows:

> The model of the total system, including accumulation of raw materials, production, and distribution, can be used to evaluate changes in given policies. A policy change can be made in any one segment of the total process, and the impact of this change can be evaluated by the simulated operating results. This tool gives management an opportunity to test and evaluate proposals without running the risk of actually installing new approaches and absorbing the necessary costs associated with system changes.

The values of simulation which directly correlate with the purposes of this study are those of analysis, multi-variate capability, planning, and decision-making. Obviously, once the model is developed and validated, associated values will be realized. Guetzkow (1963, p. 75) reviews a final important value. "It is through simulation that we may examine possible relationships among any or all variables that we are able to put into the simulation; that is, we can use simulation as a theory-building device."

Procedural Aspects of Simulation

The review and discussion of the procedural aspects of simulation may be organized around three broad topics. First, under what circumstances is it feasible to use simulation? Second, what problems may be anticipated when simulation is employed? Third, what are the key aspects of simulation procedure?

Simulation feasibility.--Choice of simulation as the tool of analysis relates in part to the expected values that may be anticipated. Thus, the previous section provides at least some criteria for choice. For example, when multi-variate capability is desired, the choice of available tools of analysis is limited. If an investigation of dynamic relationships is desirable for planning or decision-making the choice of alternatives narrows to simulation or application of other mathematical tools, i.e., queueing theory, or dynamic programming. Elton, et al. (1971, pp. 120-21) discusses the nature of final determination.

> In brief, simulation is a means of making deductions from a mathematical model or hypothesis. As such, it is an alternative to mathematical analysis. When the mathematics is tractable, analysis is normally the most efficient means of making deductions from the model to compare with observations from the real world. However, the mathematics is often intractable, particularly when the model involves a large number of interacting variables, many of them probabilistic, and when the model is dynamic--that is, the state of the modeled system at any time depends on its states at earlier points in time.

This study encompassed an attempt to deal with the dynamic nature of a complex system in development of the simulator. Thus, simulation as the tool of analysis appeared to be a valid choice. Johnson, et al. (1967, p. 314) speaks to another aspect which is frequently employed as a criterion of choice. The issue is that of system complexity.

> Management science in general, and simulation in particular, can be useful in implementing the systems concept. Model building forces decision-makers to structure the operation under analysis as an integrated system tied together by a series of equations. The use of computers in symbolic system simulation allows treatment of large-scale, complex systems. Thus the analyst can develop a model of a group of subsystems, their interrelationships, and the total system. Such an approach provides a framework for more detailed analytical examination of various segments of the system.

In all cases, the choice of a particular alternative always involves certain trade-offs. The advantages gained from the selection of one particular method are accompanied by disadvantages not associated with the choice of the other.

Associated problems.--Selection of simulation as the tool of analysis is not without its share of associated problems which ought to be given consideration as a function of choice or certainly prior to embarking upon development.

1. Resource Requirements: Several authorities speak to the issue of resource requirements. Elton, et al. (1971, p. 138) states, " . . . it would be unrealistic at this time to expect a reasonably comprehensive model to reach a stage at which its output would have predictive power in under two to three years, with an involvement over that period of a two-to-three strong team." Hopkins

(1971, pp. 475-76) is critical of the cost of development and operation of large complicated simulation models. In concluding, he strongly suggests the use of simpler models. These findings suggest that the simulation should be reduced to manageable proportions. That is, one or two components of the system should be selected for analysis as opposed to the entire system.

2. Limiting Assumptions: The conduct of research generally requires certain important assumptions related to the nature of reality. Election of computer simulation, particularly where the focus of interest must be reduced to encompass some subset of the system, requires an assumption which is discussed by Blalock (1969, p. 73).

> A little thought should convince one that whenever a theorist decides to delimit the number of variables that he will consider--and of course this will always be necessary--he is basically assuming that the world is block recursive. More correctly, he is assuming that a block recursive model can give a reasonably accurate representation of reality. First, he must assume that variables in higher-numbered blocks can safely be ignored. Thus he cannot allow for the possibility of feedback from every other variable. In effect, his blocks must be hierarchically arranged. But he must also take some variables as exogenous, or as "givens" which his theory cannot explain. As we have seen, he must assume negligible feedback to those exogenous variables.

The need for the assumption is implicit in all research though it is seldom explicitly stated. However, in simulation analysis the researcher is repeatedly confronted with the need to deal with this problem in the formulation of mathematical relationships.

3. <u>Mathematical Formulation</u>: System identification by symbolic representation involves the issue of mechanistic versus theoretical representation. Bertalanffy (1968, p. 172) advocates an appropriate choice and provides an accompanying rationale:

> Here is a first illusion we must destroy. It is a mathematical rule of thumb that almost every curve can be approximated if three or more free parameters are permitted--i.e., if an equation contains three or more so-called constants that cannot be verified otherwise. This is true quite irrespective of the particular form of the equation chosen; the simplest equation to be applied is a power series,
>
> $$y = a_o + a_1x + a_2x^2 + \ldots$$
>
> developed to, say, the cubic term. Such calculation is a mere mathematical exercise. Closer approximations can always be obtained by permitting further terms.
>
> The consequence is that curve-fitting may be an indoor sport and useful for purposes of interpolation and extrapolation. However, approximation of empirical data is not a verification of particular mathematical expressions used. We can speak of verification and of equations representing a theory only if (1) the parameters occurring can be confirmed by independent experiment; and if (2) predictions of yet unobserved facts can be derived from the theory.

An example drawn from physical theory demonstrates the point. The principal relationship $S = 1/2gt^2$ is theoretically based on the force of gravity (the parameter) acting over a period of time (the principle variable) to predict the speed of a falling body. In contrast, the relationship which describes the second law of thermodynamics (--energy always deteriorates to a less accessible form--) is mechanistic. The relationship predicts quite accurately but the parameters cannot be confirmed by independent experiment.

4. Variation in Observational Agreement: Bertalanffy (1968, pp. 222-23) points out another simulation problem in his discussion of a principle attributed to Benjamin Whorf which has become known as the "Whorfian Hypothesis."

> We are thus introduced to a new principle of relativity which holds that all observers are not led by the same physical evidence to the same picture of the universe, unless their linguistic backgrounds are similar. . . . We cut up and organize the spread and flow of events as we do largely because, through our mother tongue, we are parties of an agreement to do so, not because nature itself is segmented in exactly that way for all to see.

Simulation models representing the same phenomena devised by different individuals are particularly vulnerable to this problem. The specific components identified as well as the elements within components and the boundaries established may well be a function of individual experience not reality. All models are suspect in this respect and in need of validation.

5. Statistical Analysis: Statistical analysis of simulation research has given rise to a host of problems and has resulted in a growing body of literature dealing with this topic. Since this topic will be reviewed separately in a subsequent sub-section no further discussion of this review, is given here.

In summary, the problems identified are major concerns for the would-be-researcher who attempts analysis of complex entities employing symbolic simulation. No attempt has been made to provide exhaustive coverage of all possible problems. Simulation as a tool of analysis is yet in its infancy and such an objective as in-depth coverage would constitute a study in itself.

Simulation procedure.--Naylor, et al. (1968, pp. 23-24) present a detailed schema of the procedures employed in a simulation study accompanied by a flow-chart displaying iterative sequences. The nine steps following have been extracted from that strategy.

1. Formulation of the problem.
2. Collecting and processing of real world data.
3. Formulation of the mathematical model.
4. Estimation of parameters of operating characteristics.
5. Evaluation of the model.
6. Formulation of a computer program.
7. Model validation.
8. Design of simulation experiments.
9. Analysis of simulation data.

The last three steps of the series are related to analysis and will be considered in a subsequent section dealing with that particular topic. The first six will be treated in sequential order beginning with the first.

1. Formulation of the problem: Naylor, et al. (1968, p. 27) suggests:

> . . . before we can begin work on any simulation experiment, two important decisions must be made. First, we must decide on the objectives of our research. Second, we must decide on a set of criteria for evaluating the degree to which our objectives are fulfilled by the experiment. Research objectives in business and economics, as well as in most social sciences, usually take the form of (1) questions to be asked, (2) hypotheses to be tested, and (3) effects to be estimated.

2. Collecting and processing real world data: Elton (1971, p. 122) reviewed the problem concerning the level of aggregation. It was determined that appreciable increases in bias, in standard error of estimates and in the difficulty of detecting mis-specified model formulations occurred at different levels of aggregation.

At the conclusion of a number of experiments, Naylor, et al. (1968, p. 28) concluded that:

a. Descriptive and quantitative information is a prerequisite to problem formulation.
b. Meaningful distillation of data may suggest hypotheses which can be used in the formulation of mathematical models describing the behavior of a given system.
c. Data may suggest improvements or refinements of existing mathematical models.
d. Data reduced to a final form may be used to estimate parameters of the operating characteristics relating the system's endogenous, exogenous, and status variables.
e. Without data it would be impossible to test the validity of the simulation model.

3. Formulation of the mathematical model: The primary concern of this step in the schema is that of achieving better system definition. A specific example of this is

given by Benchoff (1969, p. 20) who states:

> The functional relationships which describe the interaction of the variables and components of the combat area and its logistics system can be separated into two distinct groups. Each group of relationships, called a sector, provides a means of describing the behavior of that portion of the system in mathematical terms.

Naylor, et al (1968, p. 10) identifies, " . . . four well-defined elements (of mathematical models):

1. Components (sectors)
2. Variables
3. Parameters
4. Functional relationships

System identification is the term employed to describe the process whereby each of the above listed four elements is identified and related.

The variables of the system of interest may be classified as exogenous, status, or endogenous variables. They are defined as follows:

a. Exogenous variables--the independent (factor) or input variables, assumed to have been predetermined and given independently of the system being modeled. They act upon the system but are not acted upon by the system.

b. Status variables--describe the state of the system or one of its components at some particular time instant.

c. Endogenous variables--the dependent (response) or output variables of the system, generated by the interaction of the status variables and the exogenous variables according to the system's operating characteristics.

The functional relationships which compose the final part of system identification are of two kinds: identities and operating characteristics. Identities are either definitions or tautological statements about the components of the model. An operating characteristic is an hypothesis, usually a mathematical equation, relating the system's endogenous and status variables to its exogenous variables. A number of authors (Blalock, 1969; Cooper and McGillem, 1967; Naylor, et al., 1968; and Sterling and Pollack, 1968) deal with the topic of identifying functional relationships. However, further treatment of this area is beyond the scope of this study.

4. Estimation of parameters from real world data: Schmidt and Taylor (1970, pp. 479-80) define a system parameter as, " . . . a quantity which affects the performance of the system, can be predicted with certainty, but either cannot or will not be altered by those operating the system. It should be noted that a parameter need not be a constant." Blalock (1969, p. 64) notes that in models containing reciprocal causation and feedback it is questionable whether it is possible to find mathematical

procedures for disentangling the various components of the system unless the parameters can be estimated. Finally, Elton, et al. (1971, pp. 122-23) in reporting the results of a micro-simulation of market economy states:

> Starting from the initial version of the model it is possible to investigate how sensitive its outputs are to the precision with which the values of particular model parameters are estimated, or to the replacement of one particular formulation by another. These procedures can offer great savings in research effort and in the cost of data collection. To test all the individual hypotheses which go to make up a simulation model would involve designing and carrying out numerous experiments either in a laboratory environment or in the real world. To obtain precise estimates of all the model parameters can necessitate massive data collection. At any stage in the model construction it is important that resources should be employed so as to reduce the residual variation by as much as possible. In this way the model can develop most speedily to the point where it has value to management --a major tactical consideration.

5. Evaluation of the model: This step of the procedure is defined as an iterative loop in the sequential flow. In essence, the process of achieving increasingly more accurate approximations of the system through minor adjustments of certain of the elements. Blalock (1969, p. 15) states:

> We must start with a finite number of specified variables. Obviously, a good deal of thought and research would be necessary prior to the decision as to exactly which variables to include in the system. But once having made this decision, we must confine ourselves to these explicit variables, though we may introduce error terms to take care of the effects of whatever variables we have not considered. If the model proves inadequate, then we may wish to introduce additional variables or modify the model in other ways, but at least for the time being we must confine our attention to a specific set of variables.

> Otherwise, we cannot derive testable conclusions from the model. Having thus committed ourselves to this particular choice of variables, we in effect admit that had another set been selected, our model might have looked quite different. In other words, there is nothing absolute about any particular model, nor is it true that if two models make use of different variables, either one or the other must in some sense be "wrong."

6. Formulation of a computer program: Naylor, et al. (1968, pp. 239-309) provide a most comprehensive treatment of simulation languages including general programming languages such as Fortran, Cobol, and special purpose simulation languages such as Simscript, GASP, SIMPAC, and Dynamo. For the purposes of this study it is only necessary to note that language is a concern and that particular languages offer certain advantages over others. In addition it should be noted that previously programmed routines exist which have been designed to facilitate certain operations, such as square root and extrapolation of time series data.

Consideration of Naylor's procedural design concludes this portion of the review which has treated the general procedures and concerns associated with system simulation. The following two sections regarding modeling and analysis are procedural in nature but are of a magnitude which deserves separate consideration.

Aspects of Simulation Models

Boardman (1969, p. 179) states,

> In general terms, model-making involves abstracting from reality components and relationships which the observer wishes to understand. A model is therefore, simply a collection of assertions about some reality.

Naylor, et al. (1968, p. 9) are somewhat more functional as they contend, "A scientific model can be defined as an abstraction of some real system that can be used for purposes of prediction and control." The functionalistic definition appears to be less parsimonious though the "system" aspect is useful. The definition employed throughout this study interprets a model as a collection of assertions which constitute an abstraction of some real world system.

Bertalanffy (1968, p. 200) contends that,

> Conceptual models which, in simplified and therefore comprehensible form, try to represent certain aspects of reality, are basic in any attempt at theory; whether we apply the Newtonian model in mechanics, the model of corpuscle or wave in atomic physics, use simplified models to describe the growth of a population, or the model of a game to describe political decisions.

Various criticisms of the problems inherent in modeling have been leveled by different authors (Bertalanffy, 1968, Johnson, et al., 1967; Naylor, et al., 1968; and Schechter, 1971). First, the job of constructing a model of a particular system is analogous to the work of an artist (lack of control; the "Whorfian Hypothesis"). Second, abstracting and relating elements and components of the real world is an exercise vulnerable to the principle of parsimony often referred to as "Bonini's Paradox." That is, a simple model is parsimonious but may likewise represent too great a departure from the real world system of interest. The opposite extreme is a model which accurately depicts the real world system but is too complex to understand and utilize. Hopkins (1971) argues for the employment of simple models while Bertalanffy (1968, pp. 100-01) notes:

> Enthusiasm for the new mathematical and logical tools available has led to feverish "model building" as a purpose in itself and often without regard to empirical fact. However, conceptual experimentation at random has no greater chances of success that at-random experimentation in the laboratory. One would do well to remember the old Kantian maxim that experience without theory is blind but theory without experience is a mere intellectual play.

Consideration of problems in modeling and associated criticisms are useful as they give pause to the would-be modeler. The ultimate test of a model is the explanations and predictions it is able to provide. No model is conclusive. Models are at best only approximations requiring subsequent testing and correction. In close interaction between experiment and conceptualization, but not confined to either, lies the further development of a field.

Church and Ratoosh (1959, p. 158) offer a typology of models.

1. The iconic--a model which visually or pictorially represents reality (a photograph), perfect one-to-one correspondence.
2. The analogue--a model which uses one set of properties to represent a similar set of properties in another system, i.e., the analogy of water flowing through pipes as a way of explaining the flow in electrical circuits.
3. The symbolic--a model which employs symbols to designate elements and relations in a system, i.e., an equation or identity.

Simulation models vary among all three types though there tend to be fewer iconic models if in fact there are any that could be classified as iconic. Mathematical models are usually symbolic. For example, the many queueing models and the Herbart and Richardson (from: Blalock, 1969) models which will be discussed shortly. A considerable number of simulation models being developed today and in the recent past are of the analogue type.

Naylor, et al. (1968, pp. 30-32) have identified six prime considerations of mathematical representation which relate to symbolic models:

1. How many variables to include in the model.
2. General complexity of variables and relations.
3. Amount of computer time required to achieve some specific experimental objective.
4. Requisite computer programming time.
5. Validity of the model in terms of its representation of reality and ultimately the accuracy of prediction.
6. Compatibility with the type of intended experimentation.

It may be useful as an integral part of this review to consider a limited number of symbolic models in both a macroscopic sense and a microscopic sense. Herbart (c. 1800) devised one of the earliest known mathematical systems which is dynamic and demonstrates the utility of the exponential relation in growth and decay functions,

$$T = S\ (1 - e^{-t})$$

where (T) tau represents the suppressed portion of an idea in time (t) and (S) is the aggregate amount suppressed. From previous definitions it is possible to determine that the model is representative of a real world system which has been depicted as dynamic, discrete, and nonlinear.

In general, discrete systems are represented as difference equations while continuous systems require the use of differential equations. An example of a simple difference equation is the general linear regression model for one independent and one dependent variable,

$$Y_i = b_{y.x}\ (X_i - u) + u_y$$

where (b) is the regression coefficient, (u) is the grand mean, (u_y) is the mean of the dependent measures, and (X_i) is a particular value of the independent variable from which (Y_i) is to be predicted. Continuous systems by contrast (Bertalanffy, 1968, p. 56), are generally represented as,

$$\frac{dQ_1}{dt} = f_1 \; (Q_1, Q_2, \; . \; . \; . \; Q_n)$$

$$\frac{dQ_2}{dt} = f_2 \; (Q_1, Q_2, \; . \; . \; . \; Q_n)$$

$$. \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; .$$

$$\frac{dQ_n}{dt} = f_n \; (Q_1, Q_2, \; . \; . \; . \; Q_n)$$

which is the general model for a system of (n) continuous variables. A specific example of a continuous, linear system is Richardson's model of armament races between two nations (Blalock, 1969, p. 127).

$$\frac{dX}{dt} = kY - aX + g$$

$$\frac{dY}{dt} = lX - bY + h$$

Richardson's model is a two nation model where (X) and (Y) represent the levels of armaments in the two countries. (k) and (l) are defense coefficients which modify the respective levels of armaments. (a) and (b) are feedback terms which represent fatigue coefficients and (g) and (h) are constants referred to as grievance terms.

While all real world systems are continuous with respect to time, it does not follow that representation of such systems must be continuous thereby utilizing only simultaneous, differential equations. For some purposes, particularly where periodic phenomena are of central interest, it is sufficient to devise a discrete time system represented by simultaneous, difference equations. Such representation may also be dictated by the objectives of the study.

In summary, Bertalanffy (1968, p. 28) notes:

> Thus, there is an array of system models, more or less progressed and elaborate. Certain concepts, models and principles of general systems theory, such as hierarchic order, progressive differentiation, feedback, systems characteristics defined by set and graph theory, and others are applicable broadly to material, psychological and sociocultural systems; others, such as open system defined by the exchange of matter, are limited to certain sub-classes. As practice in applied systems analysis shows, diverse system models will have to be applied according to the nature of the case and operational criteria.

Analysis of Simulation Studies

In the past decade, the ability of researchers to simulate complex systems has greatly improved. Along with the improved ability have come a host of problems evolving from efforts to analyze the results of simulation experiments. The associated problems have led to a growing body of literature and to two schools of thought regarding analysis.

The first position reviewed by Elton, et al. (1971, p. 129) is typified by the view which holds that, " . . . for a complex model which necessarily contains residual errors its truth or falsity is less relevant than its degree of usefulness. This approach would preclude the application of standard statistical tests." The second position has been supported by Naylor and Finger (1967) who were among the first to advocate the use of statistical test procedures in the validation of simulation studies. The literature sometimes implies that in performing simulations the investigator is differently motivated than in other studies where simulation is not the mode of model solution. Schechter (1971, p. 79) states, "In fact, there is not--and should not be--any such distinction, . . . it is how we solve the model, not why we solve it that distinguishes simulation from other techniques."

Fishman and Kiviat (1968, p. 186) discuss aspects of discrete event simulation analysis. They contend that regarding the problems associated with analysis many of them have not yet been recognized as serious problems. The authors further provide a useful scheme for decomposing and classifying analytical problems:

> Verification, validation, and problem analysis are tasks demanding careful statistical analysis. Verification determines whether a model with a particular mathematical structure and data base actually behaves as an experimenter assumes it does. Validation tests whether a simulation model reasonably approximates a real system. Problem analysis seeks to insure the proper execution of experiments and deals with a host of matters: the concise display of solutions, efficient allocation of computer time, proper design of tests of comparison, and correct estimates of sample sizes needed for specified levels of accuracy.

The definitions posed by Fishman and Kiviatt (1968) appear to be clear and to lack discernable overlap.

However, the review of related literature revealed that use of the terms by various authors is less than uniform. Therefore, in this study verification (the quantitative aspect) will refer to the process which demonstrates to what extent the model approximates the real world system of interest, validation (the qualitative aspect) will refer to the manner in which the simulation model purports to represent the real world system of interest, and experiment will be used in the same context as that used by the authors.

Verification

In reporting the verification of a model of the economy, Holland and Gillespie (1963, p. 208) state:

> A true historical verification would require the existence of time series data on all the major exogenous variables and on all the variables used to measure the performance of the economy during periods when it was subjected to a variety of exogenous events. Moreover, the time series against which the performance of the simulation is tested should be independent of any used in formulating the model. It would also be essential that no major changes in basic parameters of the system had taken place between the periods, used for verification and those used for formulation of the model.

Naylor, et al. (1968, p. 316) suggest that historical verification is only one of two possible approaches to model verification. Verification by forecasting is a second. In this regard the authors state:

> It is our position that the ultimate test of a computer simulation model is the degree of accuracy with which the model predicts the behavior of the actual system (which is being simulated) in the future. Furthermore,

> we would argue that the possibility that computer simulation models may be able to predict the future constitutes the major source of justification for the use of computer simulation as a tool of analysis.

While the general process of what is to be accomplished in verifying a model is relatively clear, the methods to be used are not. That is, various methods (Chi square, regression analysis, etc.) are employed by different investigators to measure goodness-of-fit, but there appears to be no clear-cut pattern of what is acceptable or valid under the circumstances. Cohen and Cyert (1961, p. 121) write:

> Although the final details have not yet been adequately developed, there appears to be at least three ways in which the validation (verification, by previous definition) problem for process models can be approached. First, distribution-free statistical methods can be used to test whether the actual and the generated time series display similar timing and amplitude characteristics. Second, simple regressions of the generated series as functions of the actual series can be computed, and then we can test whether the resulting regression equations have intercepts which are significantly different from zero and slopes which are significantly different from unity. Third, we could perform a factor analysis on the set of generated time paths and a second factor analysis on the set of observed time paths, and we can test whether the two groups of factor loadings are significantly different from each other.

The absence of comprehensive theory for statistical analysis of computer models insofar as verification is concerned is not however, sufficient reason to avoid analysis. One must accept, however, that at present each research effort will be judged independently until the time when a sufficient body of information is available to give direction to future efforts.

Validation

The problem of validating the model, of demonstrating the validity of the mathematical representation of the real world system of interest is considerably different. Clarkson (1962, p. 63) states:

> In the case of (verification of) simulation models the model as a whole can be subjected to statistical tests by matching the time series generated by the model against the actual time series of the variables under consideration. In this way a measure of "goodness-of-fit" can be obtained on its ability to predict the time series. The problem of testing the mechanism employed by the model is not so simple because there is no clear way of either testing the functional form of the equations or the estimates of the parameters.

Schechter (1971, p. 84) adds:

> It is not unusual for the investigator to act as the final arbitrator concerning the reasonableness of his model, basing his judgment on partially subjective criteria. Validation thus remains one of the most acute and timely problems in simulation . . .

As one approach to this problem several authors (Dutton and Starbuck, 1971; Elton, et al., 1971) are recommending thorough reporting of the variables and relationships as well as the computer program which represents the simulation model. McMillen and Gonzalez (1965, pp. 498-99) state:

> The manner of treating these tactical problems should be described when reporting simulations, along with the description of the model and its output. Criticism of methodology will continue, and for the present each simulation will be judged in terms of its credibility and utility.

Experimentation

Analytical experiments with simulation models continues to be another area of ferment and agitation. There is controversy between the two schools of thought, such as, the experimentalists and the non-experimentalists. Within the experimentalist's group there are those who favor and defend the use of one procedure over another and those who employ or accept any procedure on the basis that such practices cannot be openly debated until they have been employed.

Van Dusen (1969) and Benchoff (1969) for example, present no statistical analysis of the simulation models in their studies. Bonini (from: Dutton and Starbuck, 1971) uses a factorial design and others have employed factor analysis, analysis of variance, and multi-variate analysis techniques. An important focus of controversy is the matter of independence in stochastic models (as opposed to deterministic models). Fishman and Kiviatt (from: Dutton and Starbuck, 1971, p. 595) contend that random number generators do not produce independent numbers but in fact result in unwanted correlation.

Stochastic models introduce random variation into the simulation and use this variation as part of the argument for employment of certain techniques. In this regard Schechter (1971, p. 84) writes:

> Furthermore, when the generated data are stochastic in nature and behave according to certain assumptions (mainly, independence, normality, and homogeneity of variance), it becomes possible to use two powerful statistical techniques of data analysis--analysis of variance and regression methods.

Two immediate problems arise from this approach to simulation experiments. First, if the methods are applicable to stochastic models are they also correct for deterministic models? No answer to this question was found in the literature. Further, most if not all published accounts considered in this review spoke of simulation analysis in a general way. That is, clarification was not made regarding whether or not the model of interest was stochastic or deterministic. In the event that one cannot make a determination (at least from the review of the literature), one course of action would be to refrain from employing controversial methods or any method at all. In essence, this would amount to pursuing a course of action recommended by the non-experimentalist school and assumes statistical techniques are not permissible for deterministic models.

The researcher chose to adopt the alternate position, that is, such techniques are permissible, or at least, ought to be employed until such time as they are proven to be inappropriate. This, in effect, is an adoption of the experimentalist's view and, while it is venturous, there is at least opportunity for criticism. This is held to be of velue in and of itself, thought it leads to the second problem associated with utilization of these methods. How then does one procede with design of the experiment given no previous theory as a guide to follow and with the understanding that such methodological use may be in error?

Naylor, et al. (1968, p. 318) suggests a possible strategy for design:

> . . . we do not feel that the limited success achieved thus far by computer simulation models in terms of forecasting ability reflects some fundamental underlying deficiency in the technique itself. Rather, we strongly suspect the principal difficulty stems from the limited experience that has been accumulated by researchers using this technique. There is also the further limitation imposed by the speed and memory capacity of existing computer hardware. However, we remain optimistic on both of these points, conjecturing that these are short-run problems that man is capable of dealing with in due time.

Design and procedures of the study will be elaborated upon more fully in a later part of this study. However, it will be seen that the foregoing discussion relates directly to the nature of this study which involves a test of the means of various forecasting techniques. More will be said of forecasting in relation to the information needs of planners in the final section of this review which follows. Regarding the planned test of means, McMillen and Gonzalez (1965, p. 498) state:

> The use of classical analysis of variance seems widespread in simulation, despite the awareness that the null hypothesis may be improper, and that independence of samples is often assumed when, in fact, because of common starting conditions or because of use of a common sequence of exogenous events, dependence is the case.

Sterling and Pollack (1968, pp. 499-500) discuss aspects of the assumptions underlying the use of classical analysis of variance techniques and suggest the following:

> The analysis of variance requires that the population from which measurements are drawn be distributed normally. This latter assumption may be tested in a number of ways. The investigator could inspect a histogram of his scores or even subject the frequency distribution to a test of goodness-of-fit to the normal distribution. When the assumption of normality of distribution is rejected, the investigator could take recourse to "normalization" by a number of transformation functions (logs, square roots, arcsins, etc.). It speaks for the robustness of analysis of variance, however, that although normalcy of distribution is required, the F ratio will not be affected appreciably unless there is a considerable skew in the distribution. One other assumption is that within the group variances are of approximately equal size. If variances should differ considerably, it can be shown that the value of F will be increased spuriously.

In summary, where statistical analysis of simulation experiments is concerned, there is divided opinion regarding the wisdom of employing statistical procedures or not analyzing the research at all. If one adopts the position that such experiments should be analyzed, if for no other reason than to provide a subject for criticism, then a review of previous works is necessary. The review has revealed that most reported efforts deal with stochastic not deterministic simulations or do not clearly indicate which is the case. Lacking a documented base from which to procede two alternatives were considered. The investigator adopted the alternative of employment of statistical analysis if only to provide a basis for future criticism. In this respect, the design of the study may be viewed as venturous but it is contended that such a step is necessary at this point in the resolution of the problem and may be beneficial to future efforts.

Organizational Planning

An important part of the overall effort of this study relates to improved rational planning in educational systems. Specifically, if one assumes that student population levels act as a primary demand for certified professional staff, what can the analysis of student population levels provide in terms of information about the number of trained professional staff that will be needed. In this regard, it was believed that a review of literature related to this topic was necessary in this study. The objectives of this part of the review were: to examine the nature of planning; to review specific techniques employed in planning; and to examine previous efforts which had utilized similar methods of forecasting.

The Nature of Planning

A number of authors (Blalock, 1969; Churchman and Ratoosh, 1959; Johnson, *et al*., 1967; McNamara, 1971; and Mauch, 1962) deal with various aspects of the planning function. Johnson, *et al*. (1967, pp. 23-24) state:

> With a more dynamic environment and large, complex units operating in the face of many forces restricting flexibility, the planning function becomes critical and must be thought of on a total-systems basis. Herein lies the primary contribution of the application

> of the systems concept to planning; the organization is viewed as an entity, its major responsibility one of planning the integrated activities of all the sub-systems.

Mauch (1962, p. 158) contributes the following:

> A school system is rationally organized to the extent that it allocates resources among possible alternative uses in such a way as to get the most highly valued return for the resources expended. One possible way to get more from our educational resources--that is, to increase efficiency--is to compare alternative methods of reaching a goal.

Finally, McNamara (1971, p. 421) concludes:

> . . . the primary purpose of educational planning is to design educational policy, studies in this area include such diverse topics as curriculum selection, design of physical facilities, resource allocation strategies, cost accounting, salary schedule and analysis and student population projections.

Johnson, et al. (1967, p. 21) provide additional insight regarding functional aspects as they contend:

> Although all the managerial functions (Planning, Organizing, Communicating, and Controlling) are interrelated and the manager undoubtedly performs each at one time or another any given phase of organizational activity must start with planning. Planning is the process by which the system adapts its resources to changing environmental and internal forces.

McNamara, (1971, p. 420) however, presents an updated, composite view of planning which differs from that taken by Johnson, et al. (1967):

> Characteristic of most recent descriptions of educational planning, however, is that planning was presented as a process of preparing information in the form of a set of alternatives (with estimates of their consequences) to aid decision-making for management policy formation and administrative action.

In summary, Johnson, et al. (1967) suggest that the wholistic or systems approach to planning is a viable strategy and Mauch (1962) speaks to the issue of rationality in allocation of resources among alternative choices. Finally, McNamara's (1967) interpretation is considered the more useful for the purposes of this study and is additionally, more representative of current thinking.

Forecasting

Johnson, et al. (1967, pp. 40-41) speak to the importance of heuristic devices capable of reducing the search for solutions.

> Much of the progress in the application of computers to decision-making has been through utilizing algorithmic methods for finding problem solutions. Algorithmic methods call for the total, systematic search for solutions and have been described as the "brute-force method" of problem solving. Increasingly, interest has grown in the application of heuristic methods in decision-making. A heuristic is a strategy, rule of thumb, simplification, or any other device which drastically limits search for solutions to a reasonable process. Given the great complexity of planning and decision-making in complex organizations, the development of knowledge about heuristic processes and the creation of computer programs utilizing heuristic rather than algorithmic methods offer very interesting possibilities.

The development and testing of computer simulation models is important because it is a heuristic device and because it is one of the few methodological approaches which can encompass the dynamic aspect of time series analysis. Such a device makes possible a forecasting technique which is capable of handling the mathematical analysis which may otherwise be intractable and which permits forecasting which is not purely mechanical but predictive in the sense that it is derived from grounded theory.

The appeal of more mechanistic devices is their inherent simplicity. Heald and Moore (1968, pp. 282-84) discuss several methods of population forecasting that are recommended to practicing educational administrators for planning purposes. Salzman (1968) presents a thorough discussion of commonly accepted forecasting methods which have been employed extensively in economics. In a more particularistic sense, Costa (1970) has employed the method of moving averages and exponential smoothing to predict teacher turnover in selected schools in Iowa. Because these two methods will be used in this study it may be useful to consider them further.

Costa (1970, p. 6) defines the method of moving averages as, " . . . a forecasting technique which gives equal weight to as many previous years as desired." That is, a three year moving average may be defined as,

$$F\ (3) = \frac{L_{t-2} + L_{t-1} + L_t}{3}$$

where (L) is the level of magnitude of the variable of interest at three successive time periods (t-2, t-1, and t) respectively. In this way, a series of forecasts can be derived.

$$F_1(3) = \frac{L_{t-2} + L_{t-1} + L_t}{3}$$

$$F_2(3) = \frac{L_{t-1} + L_t + L_{t+1}}{3}$$

$$F_3(3) = \frac{L_t + L_{t+1} + L_{t+2}}{3}$$

Costa (1970) adopts a definition of exponential smoothing as follows:

$$\tilde{ET}_t = a * (ET_{t-1}) + (1-a) * \tilde{ET}_{t-1}$$

where $\tilde{ET}_t$ is the desired current estimate of turnover at time (t), (a) and (1-a) are weighting factors, (ET_{t-1}) is the actual turnover one time period in the past. The method is called exponential smoothing (Costa, 1970, pp. 9-10), " . . . because of the fact that with increasing time over successive periods the effect of earlier forecasts diminishes exponentially."

The critical problem in employment of these methods as opposed to those suggested by Heald and Moore (1968) is that they forecast only one time period in advance and then must be given an update of new information. In this respect, unless they can be modified they are of little use to planners whose needs may range from five to ten years (long-term planning). Fortunately, there are modifications of both methods which are simplistic and which effectively combat the tendency of moving averages and exponential smoothing to tend toward a static level if given the most recent forecast as the new update.

As a last consideration related to population forecasting, one must consider what variables are important if simulation is employed as one strategy for achieving predictions? Blalock (1969, pp. 37-38) offers insight to this problem in concluding that:

> . . . population change is a simple additive function of four variables: birth rates, death rates, and rates of immigration and emigration. The major theoretical task in explaining population change is that of finding the determinants of each of these intervening variables.

In summary, this section of the review has considered the importance of heuristic devices which can facilitate the needs of planning and which is an accepted function of managers of complex organizations. At present, there are a number of methods for attaining future projections, most of which are mechanical and some of which are limited in the range of projections that can be obtained. Most methods offer simplicity of utilization in return for the known limitations. Simulation is viewed as a trade-off. That is, complexity of development is accepted, though this is a one-time problem, accuracy and range of projection in addition to being grounded in theory are the benefits to be derived.

Summary

An extensive review of the literature was necessary because of the large number of salient aspects of simulation research, the short period of time in which development has occurred, the large number of recent efforts, and the fact that few aspects have been covered in-depth. Thus, it was necessary to consider many aspects as opposed to a brief survey of the field and intense focus on the primary topics.

Examination of the theory of general systems provided a framework for conceptualization of the organization as system. The theory included a number of concepts which were pertinent to the central interest of this study. In particular, "stress" was operationalized as a primary drive in the organization and the "process" by which the organization adapted to this stress became the aspect of reality which was to be simulated.

Extensive review of the technological aspects of computer simulation provided a foundation for model development and computer programming. Until the model was under construction it was impossible to ascertain which particular analytical procedures would be employed nor from what alternatives the choices would be made.

Finally, it was necessary to deal with rational planning. Planning is a primary function of management in any organization. Simulation as a tool of analysis permits wholistic analysis encompassing the many variables of the system. Therefore, predictive information attained through simulation was expected to be at least as accurate as forecasts achieved by other methods. In addition, there is evidence to indicate that simulation models can provide insight into complex organizational process.

The procedures of the study to be presented in Chapter III make use of the findings of the review of literature as a foundation for design and development of the model and as a guide for analysis.

CHAPTER III

TECHNIQUES AND PROCEDURES

Chapter III presents a description of the techniques and procedures that were employed in this study. Organization of the chapter follows the nine steps identified by Naylor (1968) and discussed in the review of the literature. Because of the developmental nature of the study and the tool of analysis employed, the Naylor schema was found to be a useful format for reporting the techniques and procedures of this study.

Formulation of the Problem

Conceptualization of the system of interest and determination of the level of aggregation were major concerns in the formulation of the problem. In this respect, the university model developed by Koenig, *et al.* (1968, p. 9) was useful as a means of suggesting primary components of educational systems. Appendix A provides a schematic of the model presented in the authors' report.

As suggested by Elton, et al. (1971) and Hopkins (1971), reduction of the focus of the study was mandatory. Therefore, the university model was modified and the schematic representation was reformulated to provide the representation which is included as Appendix B. The four components depicted in the modified schematic were initially considered for inclusion in the study and were subsequently rejected as still exceeding manageable proportions. Therefore, attention was ultimately focused on that portion of the system included within the area defined by the dotted line (see Appendix B) and the remainder of the system was left for future efforts. The components of interest were therefore limited to the student population component and the professional staff component.

The determination of the level of aggregation was based on three considerations. First, development of a system of education is constitutionally the responsibility of the state. Policies developed at this level are uniformly applied in all districts thus eliminating a problem of inter-system variation. Further, insofar as the process model was representative of a particular school district it would be representative of all local school districts. Second, the State Department of Education offered the advantage of providing a large body of standard data requisite to development of the simulation (McNamara, 1971). Third, if the study had been focused on the local district level with its considerably reduced body of data (in comparison to the state public school system as a whole), the question may have been raised regarding whether mathematical analysis as opposed to simulation might not have been more efficient. In this regard, the capacity of modern computers for massive data storage and computational performance is a technological resource particularly suited to a problem aggregated at the state level.

At this point in problem definition, two possible orientations existed as alternatives to simulation development (Cooper and McGillem, 1967, p. 9). That is, one might have elected systems analysis which would focus interest on an attempt to identify the organizational process which relates given inputs to outputs. Or, one might have elected the course of systems design in which attention would be concentrated on development of an ideal process to achieve desired outputs given stated inputs to the system.

In this study, the investigator elected the course of systems analysis. Attention was thus focused on the existing process within and between the student population and professional staff components as sub-systems of the state public school system in Michigan. Furthermore, it was necessary to invoke the assumption regarding the "block-recursive" nature of the organizational system which was discussed by Blalock (1969) in the review of the literature.

Pheiffer (1968) concluded that identification of the boundaries of the system of interest was a prerequisite to problem definition. Blalock (1969) suggested that population change is an additive function of birth rates, death rates, and rates of immigration and emigration. Since the components of interest were both population sectors, i.e., student population and professional staff population, Blalock's suggestions were employed in this study with few modifications. These are discussed in the section which deals with formulation of the model.

Collection and Processing of Data

The collection and processing of data had implications for both problem formulation and formulation of the model. That is, collection and processing of data completed an iterative loop which at certain stages resulted in problem clarification or modification and, at other times identified a need for additional empirical evidence necessary to further progress in model formulation. This frequently occurred during model formulation as attempts were made to decrease the difference between simulated response and real world behavior.

Michigan birth rate data was obtained from the Michigan State Department of Health. The data was obtained for the years 1940 to 1971 inclusive and is presented in Appendix C. Age specific death rates were obtained from the Commissioner's Standard Mortality Table (1958) and are included as Appendix D of this study. The age specific death rates as given by the table are not computed for specific geographic regions (states) and were not weighted or altered to allow for a primarily rural or a primarily metropolitan state.

For the purposes of computer simulation it was necessary to consider birth data since 1940 because the simulation program required at least seventeen years of compressed time model operations to produce a simulated K-12 school population. This procedure yielded a K-12 student population by 1957. For the experiment, K-12 simulated population levels were required for 1959-1968.

Student population data for the public elementary and secondary schools in the State of Michigan were necessary as a standard against which the model could be verified. For this purpose, the investigator utilized Fourth Friday Report data (1950-1957) made available by the State Department of Education in Michigan (MSDE).

Data associated with the professional staff component were derived from several sources. First, currently employed totals of professional staff were available from the State Department of Education in Michigan (MSDE) and had been derived from the annual Personnel Report (1950-1970) required of all public school districts in Michigan. Second, data related to the production of professional staff by certificate area was obtained from a series of three reports produced by the State Department of Education in Michigan (1968-69). Further, the MSDE had produced a study of teacher supply and demand (1971). Data from this study was useful in establishing net in/out migration estimates of certified professional staff and one estimate of the functional supply-demand rate for currently employed professional staff.

Formulation of the Model

Formulation of the model was appreciably dependent upon identification of the elements of mathematical models defined by Naylor, et al. (1968), upon the critical variables in population studies as identified by Blalock (1969), and upon the clarification of types of simulation models as presented by Cooper and McGillem (1967). All of the aforementioned were discussed in the review of the literature.

Model Characteristics

First, the system of interest as previously defined was conceptualized as discrete, linear, dynamic, and deterministic. While to some extent the "Whorfian Hypothesis" may have been active the assumptions are not without some basis.

A discrete model was planned because the real world system of interest reports data for major variables on an annual basis and the amount of change in these variables for shorter time periods was considered negligible.

Linearity was assumed for the sake of simplicity even though considerable evidence would suggest that populations, in particular, are more appropriately described by exponential (non-linear) functions. In support of this assumption, a Pearson Product-Moment correlation was computed and revealed a correlation of (.93) between reported student census data and reported professional staff for similar years (1959-1970). The linear regression coefficient was .0171 with a sample standard error of estimate of 2,990. Procedures recommended by Hays (1963) were employed in the analysis.

The model incorporated time as a basic system parameter (the dynamic aspect) in order to take advantage of a primary benefit of simulation. That is, most static models employ computed survival ratios or a similar scheme which circumvents the necessity of considering the time dimension; thereby, avoiding the large number of computations that are necessary when time is taken as a parameter of the system.

Finally, the model was conceptualized as a deterministic system because the basic problem of required planning predictions dictated a need for point estimates over the planning period as opposed to interval estimates.

Component Elements

Naylor, *et al*. (1968) defines the elements of mathematical models as the components, the variables (status, exogenous, and endogenous), the parameters, and the functional relationships. Blalock (1969) suggests, that where populations are concerned, the primary variables are births, deaths, and in/out migration. Identification of the system required that these two sets be associated and specifically identified for each component of the system. Specific identification of model elements and the operating characteristics will be discussed under model validations in Chapter IV.

Estimation of Parameters

Estimation of parameters for the purposes of this study included both identification and estimation. In all cases, parameters were estimated from empirical evidence. However, some parameters were subsequently adjusted during later stages of model development when the technique of sensitivity analysis was employed (see Figures 1 and 2 for examples of the effects of parameter changes).

No attempt was made to review the sources and methods of estimating all model parameters for two reasons. First, sources employed were discussed under a previous section entitled "Collection and Processing of Data." Second, for the purposes of study replication the computer program is readily available and within that program exact values of the parameters are stated. Thus, exact study replication is always possible and parameter values may be extracted and compared against real world standards for evaluative purposes.

Model Evaluation

In this study, model evaluation (verification) was accomplished only after system components and elements had been identified and a basic computer program had been written to generate K-12 school-age populations given calendar year birth data (1940-1971) and age specific death ratios.

The computer program was designed to generate school-age (5-18) populations for the years 1957-58 through 1974-75. After generating the population estimates, the technique of sensitivity analysis was employed using the mathematical equations which represent the system to test the effects of various combinations of parameter values and to compute the magnitude of differences between simulated and real time series data.

Given parameter values that had been identified from previous studies (MEA, 1971; NEA, 1970) or estimated from empirical evidence (Fourth Friday Enrollment data; Professional Personnel Data) as initial statements about the real world, an iterative process of parameter modification and solution of the mathematical model attempted to achieve successively better approximations of real world behavior. The objective of this effort was to test the mathematical model for relative accuracy prior to final computer program formulation, thereby avoiding extensive reprogramming.

Model verification procedures consisted of alternately adjusting system parameters and testing the simulation output which consisted of the primary endogenous variable response (employed professional staff). The statistic employed was Thiel's U which was used in a similar fashion by Tsao and Day (1971, p. B-603).

Thiel's U is a variation of the standard goodness-of-fit test. That is, the statistic varies in value from zero to one. The closer the value is to zero, the stronger is the inference that the computer generated time series approximates the desired real world response. Tsao and Day (1971) selected a particular value of the statistic as an a priori criterion of model acceptance. This study used successive values of the statistic as a guide to determine when parameter modifications were effective, such as, resulting in lower values of the statistic indicated when modifications were ineffective. Time and resources were the ultimate constraints on sensitivity analysis and the particular value of the statistic that was accepted prior to conduct of the experiments.

Formulation of the Computer Program

The review of the literature revealed two alternative courses of action regarding programming. That is, one could employ any one of the numerous special purpose simulation languages (GASP, Simscript, and others) or one could employ a standard language (Fortran, Cobol, APL). The decision to employ Fortran IV in this study was based entirely on the fact that most hardware systems will have a fortran compiler. Therefore, the program could be adapted to the greatest number of systems given that adequate storage and central memory were available.

The system on which programming was completed consisted of the Michigan State University, CDC-6500 system which has the capacity for Model 33 teletype terminal interaction. Programming and testing used the remote terminal because this permitted minimum turnaround time and increased overall programming efficiency. A minimum number of library sub-routines (such as square root) were employed so that modification for use on other systems would be minimal.

Finally, where possible modular construction of the simulation vehicle was employed. That is, interaction within and between components and sub-routines related to model evaluation were kept separate wherever possible. The final product was a program consisting of only the simulator and the model elements previously discussed (see Appendix E). Given a particular array of inputs (birth data) the program will generate a deterministic set of outputs representing employed professional staff and required staff replacement estimates.

Model Validation

The problem of model validation as discussed by Clarkson (1962) is more appropriate to the following chapter which deals specifically with analysis. However, the approach suggested by Schechter (1971) was employed. That is, the mathematical representation was related to real world components and elements and a rationale presented in support of the mathematical relationships included in the model. The questions that are pertinent to the analysis are as follows:

1. What assumptions are inherent in the model and what are the implications of these assumptions for the study?

2. What components of the system of public school education in Michigan have been incorporated in the model?

3. What variables have been defined as exogenous?

4. What variables have been defined as endogenous?

5. What are the operating characteristics of the system? Particularly, what are the relationship(s) that unite distinct components of the system?

6. What are the status variables which represent the state of the system over time?

7. To what extent was the design limited by factors beyond the control of the investigator? (For example, the choice of values of a particular parameter when real world data was not available.)

8. What is the nature and extent of any departures from intended design and/or the real world; and, what implications do these departures have for the simulation?

Design of Simulation Experiments

Two experiments were conducted to test the capability of the model to provide more accurate planning information than that which could be obtained through use of conventional methods, such as, the method of moving averages (2 years) and exponential smoothing ($\alpha = .8$). The latter techniques are currently used primarily by economists to make predictions for the business sector.

Design of both experiments employed a one-way, fixed effects analysis of variance (Hays, 1963).

Treatments were simulation, moving averages, and exponential smoothing. The dependent variable was professional staff population levels (as forecast by different treatments, i.e., methods) and the experimental unit was years. The critical level of alpha was selected at (.05) since the risk of error for the purposes of this study was considered to be a minimum problem with few accompanying, serious consequences.

For the first experiment, the hypothesis to be tested was:

> H_1: There is no difference between the predictions generated by a simulation model and those achieved by moving averages and exponential smoothing.

> H_2: There is a difference between the predictions generated by a simulation model and those achieved by moving averages and exponential smoothing.

Both the method of moving averages and exponential smoothing have serious limitations in terms of ability to provide long range predictions for planning purposes despite the current popularity and ease of use of these methods. That is, both methods can predict only one year in advance and then must be given a new information update. The first experiment was a test of ability to provide short-range planning forecasts. The experiment offered every possible advantage to the conventional methods by providing a true information update each year for a ten year period (the planned duration of the collapsed time experiment). In so doing, the experiment was planned as a maximum test of the simulation vehicle.

The second experiment assumed that ten years of planning data was required and that each of the methods would be compared without special advantages. That is, a modification of the two forecasting techniques was necessary in order to provide such data.

Modification of the forecasting techniques was achieved by providing an update based on the last forecast increased by the mean gain over the five years prior to the experimental period (1954-1958). Justification of such a procedure was based on retention of the ease of use provided by each of the conventional methods. In contrast, simulation requires a long period of development and considerable resources. The essence of the second experiment was related to the capability of one or more of the methods to provide more accurate planning data. It is believed that a better decision could be made regarding which method to employ given the relative accuracy of each of the methods, as well as related advantages and disadvantages. Design of the second experiment was similar to the first. The hypothesis to be tested was:

H_1: There is no difference between predictions generated by simulation and those achieved by modified forecasting methods.

H_2: There is a difference between the predictions generated by simulation and these achieved by modified forecasting methods.

The use of analysis of variance to examine the hypothesis of equal means in each experiment required consideration of three underlying assumptions. The F statistic is robust to violations of the assumptions of normal distribution and equality of variance for the dependent measure. However, the F_{Max} test for equality of variance (Walker and Lev, 1953, pp. 191-95) was used (alpha = .05) to examine the strength of the latter assumption.

The third assumption of independence was considered questionable and therefore, the following linear transformation of dependent measures was used:

$$d_i(t) = P_i(t) - A(t)$$

where, $d_i(t)$ represents the difference between the predicted score derived from a particular treatment and the actual real world value for a given year. If the null hypothesis was rejected in either experiment, pair-wise comparisons were planned to examine the differences between means using the Scheffé method as described by Hays (1963).

Summary

The procedural plan of this study involved five sequential steps. First, the development of the model which included problem formulation, collecting and processing of data, system identification (formulation of the mathematical model), and estimation of parameters and operating characteristics. Second, formulation of the computer program. Third, evaluation of the model (verification) which employed sensitivity analysis and the use of Thiel's U statistic as a guide to model improvement. Fourth, validation of the model accomplished through a series of questions formulated to provide an analysis of model structure in terms of the related real world system. Finally, two experiments were planned to compare the accuracy of the predictive capacity of the model against two conventional forecasting techniques.

The procedural plan followed the nine step schema proposed by Naylor, et al. (1968) almost without exception. The ninth step, however, dealing with the analysis of simulation data was postponed to Chapter IV of this study.

CHAPTER IV

REPORT OF FINDINGS

The report of findings is organized around three topical areas as suggested by Fishman and Kiviatt (1968) followed by a summary which relates the three areas. Validation of the model is the first area and involves a review of the development of the model followed by an explanation of structural elements and relationships in terms of real world correspondence. The second area is model verification which concerns the simulated response of endogenous variables as compared to real world behavior. The third area is an analysis of findings for two experiments which were conducted using the simulation vehicle.

Model Validation

Model validation concerns a presentation of the model accompanied by appropriate explanation of the elements of the model in terms of real world counterparts. For the purposes of this section the development will be described first. Next, variables and operating characteristics will be defined. Finally, the mathematical model will be presented with accompanying explanations and previously formulated questions will be answered regarding the model and the real world system of interest.

Model Development

The development of the model and the planning and conduct of this study was not a straightforward procedure as might be inferred from the carefully constructed schema suggested by Naylor (1968). That is, at some time or another the study progressed through each of the identified stages. However, the development of the model often required looping back to previous stages in order to attain subsequent refinements or to implement desired modifications. A brief review of these developmental phases may be useful to future efforts.

The public school system in Michigan was first analyzed from a wholistic point of view. Over a period of time, important components became distinguishable and attempts were made to diagram the components and hypothesized relationships between components (see Appendix B). The foregoing iterative sequence was replaced by a similar loop which first examined individual elements within components followed by tentative formulation of hypotheses about the nature of relationships between elements within a particular component. This process was followed by a more detailed diagram of systemic relationships.

As components and elements of the system were identified, time series data related to important elements of the system were collected and analyzed. A Pearson Product-Moment correlation ($r = .93$) was calculated to examine the nature of the relationship between student populations and teacher populations which was critical to this study.

The next phase was formal identification of the system and development of the mathematical model. First, elements within components were given variable names and defined. Second, equations were formulated that closely corresponded to the former hypotheses about the nature of relationships. Third, an attempt was made to test the equations for correspondence to real world behavior. In some cases, the functions were rejected and subsequently reformulated. In other cases, new data were collected to provide required input to the model. Finally, different relationships were peremptorily tested to provide explanation of inter-component behavior. At this point, the model had been completely identified and formulated, though a number of iterations were subsequently necessary to reach the final stage.

Development of the computer program using Fortran IV proceeded rapidly because of the mathematical nature of the model; at least one complete program was rejected before the final program was formulated and tested. Use of the computer terminal for program testing was especially efficient, since considerable turn-around time between computer runs was avoided.

The last phase of development was concerned with achieving successively improved performance. Once again, a number of iterations were necessary as parameters were altered and time series data were re-generated and compared with real world data. Final comparisons indicated that the model was performing satisfactorily and the two, planned experiments were conducted.

Variable Definitions and Operating Characteristics

In the process of model identification the following elements were identified and given specific variable names.

1. Student population component.
    a. Birth(t)--birth rates for years 1940-1971
    b. Surv(t)--surviving population after death losses
    c. Dth(a)--age specific death rates
    d. SPOP(t)--student populations for grades (K-12) by years
    e. P1--net in/out migration factor
    f. P2--private school population factor
    g. P3--drop out factor

2. Professional staff (teacher) component.

   a. AvStf(t)--total available staff

   b. InProd(t)--number of teachers produced by training institutions per year

   c. InPool(t)--number of teachers qualified to teach but remaining inactive by choice

   d. Attr(t)--losses due to death, retirement, and for other reasons

   e. NMigr(t)--number of teachers who migrate in or out of the State of Michigan

   f. TPOP(t)--number of teachers currently employed

   g. NStaff(t)--number of teacher replacments needed

   h. ElmStf(t)--number of elementary replacements needed

   i. SecStf(t)--number of secondary replacements needed

   j. P6--elementary replacement rate parameter

   k. P7--secondary replacement rate parameter

3. Interdependency Parameter.

   a. P4--approximate student/teacher parameter

4. Operating characteristics.

   a. Student sector--

   SPOP(t) = SPOP'(t) + P1*SPOP'(t) - P2*SPOP'(t) - . . . - P3*SPOP'(t)

b. Professional staff sector--

$$AVSTF(t) = InProd(t) + InPool(t) - Attr(t) + \ldots$$
$$\ldots + NMigr(t) + TPOP(t)$$

c. Supply-Demand function--

$$TPOP(t) = P4 * SPOP(t), \text{ where } P4 = .036$$

Model Identification

A sub-routine of the model permits calculation of a (20x31) survivor matrix by interacting birth data with age-specific death rates. The unrefined sum of (K-12) student population for a given year was then obtained by summing across 13 columns beginning with students of the 1940 birth group who were 17 years old in 1957, e.g.,

$$SPOP'(t) = 17_{1940} + 16_{1941} + 15_{1942} + \ldots + 6_{1951} + 5_{1952}$$
$$= SPOP'(1957), \text{ the first possible (K-12) population given 1940 birth data}$$

The unrefined sum of age-specific populations for each year from 1957 through 1975 is then entered into the operating characteristic of the student population sector (see above) to provide a refined estimate of student populations. Parameters P1, P2, and P3 were initially estimated at .11, .15, and .16 respectively. These were changed very little in subsequent refinements of the model.

The operating characteristic for the professional staff sector relates important variables suggested by

Blalock (1968) as does the operating characteristic for the student population sector. However, no data was found from which an estimate of the inactive pool of teachers InPool(t) could be obtained. Thus, this function is presently not operative though it has been included in the program and could be made operative simply by providing the required estimates of population dynamics.

To circumvent this problem a different approach was taken. That is, an annual estimate of required teacher replacements (.065) was computed to generate a time series for a new variable NStaff(t) from annual estimates of TPOP(t). The relation used was:

$$NStaff(t) = P5 * TPOP(t)$$

where the parameter P5 is a multi-factor point estimate of several factors including attrition, production, and movement both into and out of the inactive pool.

Given this addition to the model it was possible to generate a time series which represented professional staff needs based on actual birth data for all years from 1957 to 1975. Further, given this time series it was possible to estimate from data (see Appendix F) the proportion of replacment needs by certificate type. The functions that produce these estimates are:

1. ElmStf(t) = P6 * NStaff(t), where P6 = .485

2. SecStf(t) = P7 * NStaff(t), where P7 = .515

Parameters P6 and P7 were derived from the data in Appendix F after elimination of other types of certificates that are not expected to be used as new certification rules come into effect. The reduction of replacement needs by certificate type results in a certain amount of error for estimates prior to 1972 but seems justified in the sense that predictions of greatest interest derived from the model will be post 1972.

Examination of potential relationships which could be used for the function uniting the primary components (the supply-demand function) employed a modified version of a Fortran program formulated by Salzman (1968). The program has the capability of generating polynomial, logarithmic, and exponential equations given time series data for corresponding years on two variables of interest. In addition, a linear regression equation which had been a by-product of the Pearson Product-Moment correlation (Hays, 1963) was tested. In all, the best fit was obtained by calculating a rate parameter (P4 = .036) to represent the approximate student/teacher ratio of 24:1 as suggested by the Michigan State Department of Education study (1971).

The full simulation model, as defined, accepted birth data beginning with the year 1940 and generated estimates of student population levels from 1957 to 1975. From these estimates the supply-demand function produced estimates of the levels of employed professional staff for similar years. Finally, the model had the capability of translating estimates of new staff needed for replacement into needed certificate types.

Model Validation Questions

In Chapter III, eight questions were formulated regarding the validity of the model in terms of the real world system it purported to represent. Each question is re-stated below, followed by the answer for that question.

1. What assumptions are inherent in the model and what are the implications of these assumptions for the study?

Two assumptions were stated in the beginning of the study. The first adopted the position that student population levels presented a major stress (drive impetus) within the system. This assumption is basic to the model and is the primary basis for derivation of all values of endogenous variables. To the extent that this assumption is in error, the values of all response variables would be in error. Since relatively close values were ultimately predicted, the assumption was held valid.

The second assumption concerned the block recursive nature of the system. That is, the system as represented at the state level is assumed to be relatively unaffected by behavior at either the local district or federal level. No way was found to assess the amount of error that such an assumption contributes to derived response levels. Again, since derived values were considered acceptable, it is contended that the amount of error was negligible.

Other assumptions were made in the course of development of the model. That is, the design criteria (linear, discrete, dynamic, and deterministic) as well as the adopted values of certain influential parameters (net migration, private school population, and drop-out rates) have certainly contributed to error in the simulation vehicle. Again, since simulated behavior closely approximates real world behavior, it is contended that the total magnitude of such error was within acceptable limits.

2. What components of the system of public school education in Michigan have been incorporated in the model?

Only two components of the public school system are represented in the model, such as, the student population sector and the professional staff sector (see Appendix B).

3. What variables have been defined as exogenous?

Within the student population component, Birth(t) representing the number of births per year was the only exogenous variable. In the professional staff component, the original plan would have required that InProd(t) and possibly InPool(t) be represented as exogenous variables with accompanying input data. However, as previously explained, the lack of data forced abandonment of this scheme of representation.

4. What variables have been defined as endogenous?

Within the student population component SPOP(t) is both endogenous and a status variable. Others such as high school graduates, private school population, and number of drop-outs could easily be derived but were not necessary for the purposes of this study.

Within the teacher population component, there are three endogenous variables for which time series data is provided by the computer program. NStaff(t) provides point estimates of required annual staff replacements based on 6.5 per cent of currently employed staff. ElmStf(t) provides point estimates of the annual need for new staff with elementary certificates. Similarly, SecStf(t) provides estimates of the annual need for new staff who are certified for secondary. TPOP(t) is the primary endogenous variable of interest and is also the status variable for the professional staff sector. Time series data is available for this variable also and is used extensively in the two experiments.

5. What are the operating characteristics of the system? Particularly, what are the relationships that unite distinct components of the system?

These have been previously identified in the section which dealt with model identification. The supply-demand function that unites the two distinct components of the system as well as the operating characteristics for each sector are linear in nature. The supply-demand function in particular is dependent upon stability of the student/teacher ratio.

6. What are the status variables which represent the state of the system over time?

Within the student population component, the state of the system is represented by the number of clients to be serviced by the public school system in Michigan, i.e., SPOP(t). SPOP(t) is important both in terms of the demand for professional staff that it represents and also the demand that is posed for other resources of the system (physical facilities and financial resources).

In the professional staff component, TPOP(t) is the important status variable which represents the level of employed staff over time. Somewhat unrealistically, TPOP(t) is totally dependent on SPOP(t) in the present model. The dependency of TPOP(t) will change as future expansion of the model is realized.

7. To what extent was the design limited by factors beyond the control of the investigator?

The most serious limitation was the lack of data for the variable that represented the inactive pool of teachers. This prevented generation of point estimates for the number of available staff over time. The loss detracted from the potential of the full model since AvStf(t) is believed to be a useful variable in terms of better understanding of the need for new staff on an annual basis. Of related importance is the need to begin compiling data for both variables InPool(t) and NStaff(t) so that related measures such as AvSTF(t) may eventually be obtained.

8. What is the nature and extent of any departures from intended design and/or the real world; and, what implications do these departures have for the simulation model?

The limitation discussed in answer to the previous question was the only departure from intended design. The implication of this departure has also been discussed. There were no departures from the real world insofar as all parameter estimates and input for exogenous variables were derived from empirical findings. The assumptions previously discussed were the primary departures and these were not happenstance.

Model Verification

As time series data was generated for an increasing number of variables, correlations were derived to examine the relative ranking of both simulated time series with real world counterparts and one simulated variable with another. As a result, the following incomplete matrix was obtained for the years (1959-1968). The figures in Table 1 indicate how closely the relationships agree among actual time series and simulated time series for different variables, such as, teacher population levels (TPOP(t)) and student population levels (SPOP(t)) respectively. The first correlation as previously discussed was obtained prior to the beginning of model development to examine the nature of the relationship between primary variables in each of the two components which were to be simulated.

TABLE 1.--Relationships Between Actual Teacher Populations and Actual and Simulated Teacher, Student Populations.

Variable Time Series	Actual TPOP(t)
Actual SPOP(t)	.976
Simul. SPOP(t)	.917
Simul. TPOP(t)	.937

Table 2 compares response value for simulated teacher populations (TPOP(t)) achieved at three separate points in the overall process of sensitivity analysis.

TABLE 2.--Actual and Simulated Response for TPOP(t).

Year	Actual TPOP	1st Sim. Run	$Diff_1$	2nd Sim. Run	$Diff_2$	3rd Sim. Run	$Diff_3$
1959	58,251	64,811	5,610	59,825	1,574	55,857	2,394
1960	60,394	67,278	6,977	62,103	1,708	59,405	989
1961	63,271	70,029	6,829	64,642	1,371	63,362	91
1962	66,024	73,255	7,255	67,620	1,596	68,002	1,978
1963	68,099	76,398	8,398	70,521	2,422	72,521	4,422
1964	69,380	78,422	9,122	72,389	3,009	75,432	6,052
1965	72.935	79,596	6,696	73,474	538	77,121	4,186
1966	76,047	80,885	2,570	74,664	1,384	78,974	2,927
1967	80,637	82,015	2,240	75,707	4,931	80,599	38
1968	85,346	82,703	2,597	76,342	9,005	81,589	3,757

It is clear that observation of the difference scores would have been sufficient guidance in the early stages of model refinement. However, experience has shown that in the latter stages of development some guidance technique was necessary to distinguish improvements. Thiel's U statistic was employed as a guide in sensitivity analysis once a complete functioning model and computer program had been attained.

Table 3 provides a comparison of the value of the U statistic computed for each of the foregoing simulated time series as well as the values of relevant parameters used in the model to achieve that series. The computer program for the revised model from which the third time series (above) was generated was used in the experiments which are discussed in the last section of this chapter. It is important to note that the relatively low values of the U statistic were not expected and that this factor almost as much as time expenditure caused early curtailment of the process of sensitivity analysis. Further, a scheme ought to be devised and employed to rapidly examine various combinations of different parameter levels. The space of all possible combinations of parameters (estimated at approximately 1,000 in this model) should have been systematically examined for possible improvement of the primary endogenous variable TPOP(t).

TABLE 3.--U Statistic and Parameter Values for Separate Simulation Estimates of TPOP(t).

Simulation Series	U Statistic	Values of Relevant Parameters			
		Net Migr. P1	Priv. Schl. P2	Drop-out P3	T/S Ratio P4
First Run	.03538	.11	.15	.16	.037
Second Run	.02589	.14	.13	.15	.039
Third Run	.02298	.14	.13	.15	.036

The parameter estimates used for the first simulation run represented mean estimates of true population parameters. That is, the estimate of net in/out migration which was obtained from data in Meyers and Van Meer (1966) was estimated at approximately (11%). Private school populations (MEA, 1971) averaged approximately 275,000 per year which was initially stated as (15%) of the total population of survivors. Employment of a point estimate for the private school population parameter (as opposed to the fitting of a curve) is believed to have contributed substantially to error in the model since this particular variable oscillates from year to year and currently exhibits a clear pattern of population decrease. A better scheme for representation of the model would have been to fit a curve to the data and then to extrapolate future predictions from the function of that curve.

Some attention ought to be devoted to the process of curve fitting which represented three restrictions for the purposes of this study. Bertalanffy (1968) has noted that such activity is no more than intellectual play. That is, curve fitting permits access to more exact point estimates but the parameters of the function will likely have no meaning in the real world. Second, functional representation of the parameters in this study would possibly have yielded a non-linear function for at least one of the parameters thereby exceeding a design limitation which clearly specified a linear model. Third, functional representation of parametric effects requires a knowledge of contributing variables, data related to those variables, and adds additional complexity to the model. The alternatives for this study were parsimony or increased accuracy. In this case, a parsimonious model was elected especially in view of the low value of the U statistic which was obtained.

Table 4 provides a comparison of the means, standard deviations, and variances for the two time series (actual teacher population levels and final-run simulation values of that variable for the years 1959-1968).

TABLE 4.--Simulated and Actual Teacher Population Parameters (1959-68).

Time Series Identity	Mean	s.d.	Variance
Actual No. of Teachers	70,038	8,751	76,580,001
Simul. No. of Teachers	69,729	5,889	34,690,321

The agreement in level (the mean) is noteworthy, though the difference in standard deviation is indicative of considerable variation in point by point comparisons as well as in the overall configuration. Figures 1 and 2 which follow illustrate these observations. Figure 1 is a comparison of first-run simulation values for TPOP(t) with actual values of teacher population levels for the

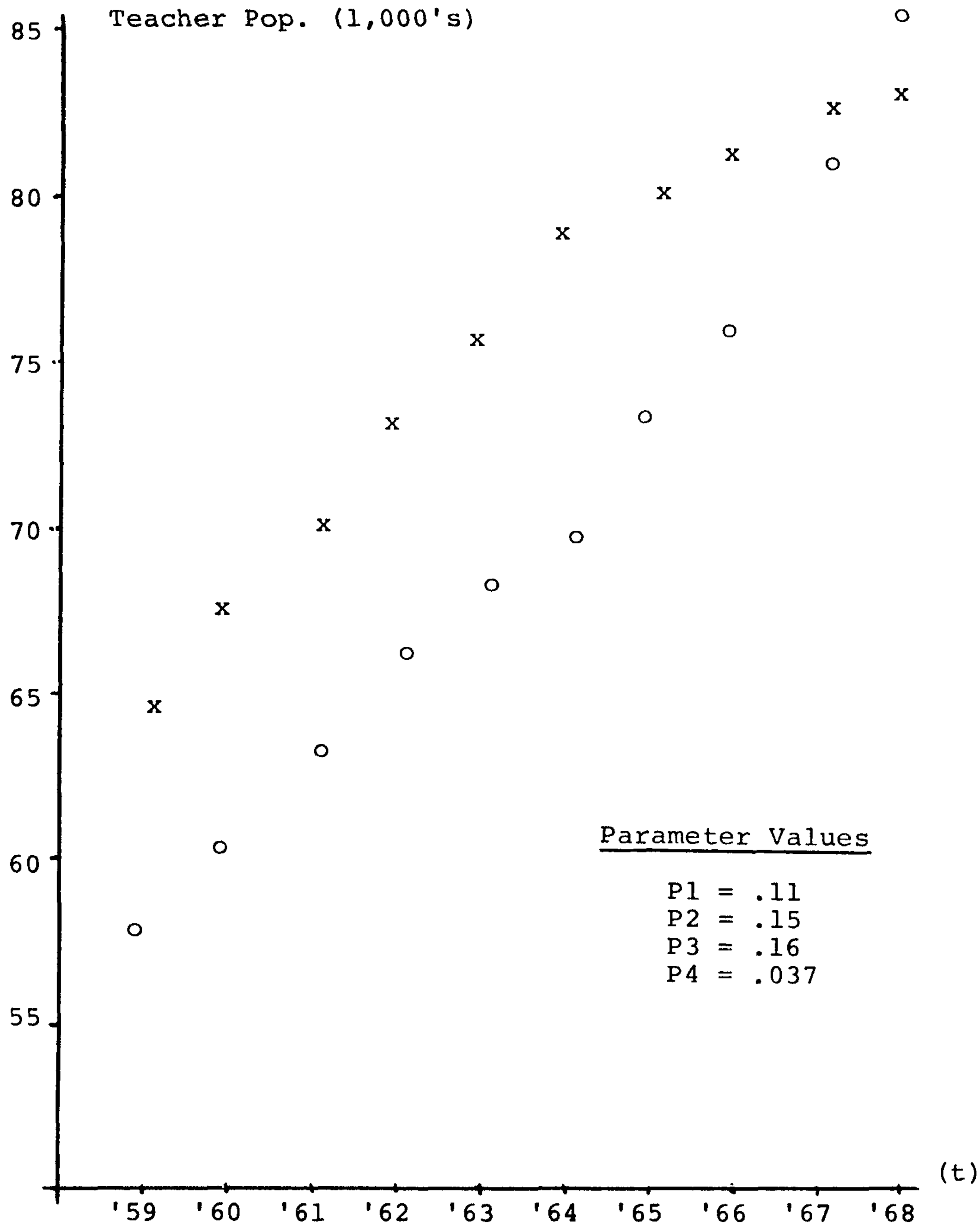

Figure 1. Comparison of actual and simulator predicted teacher populations (1959-1968).

Note: o Actual teacher populations.
x First simulation run-predictions.

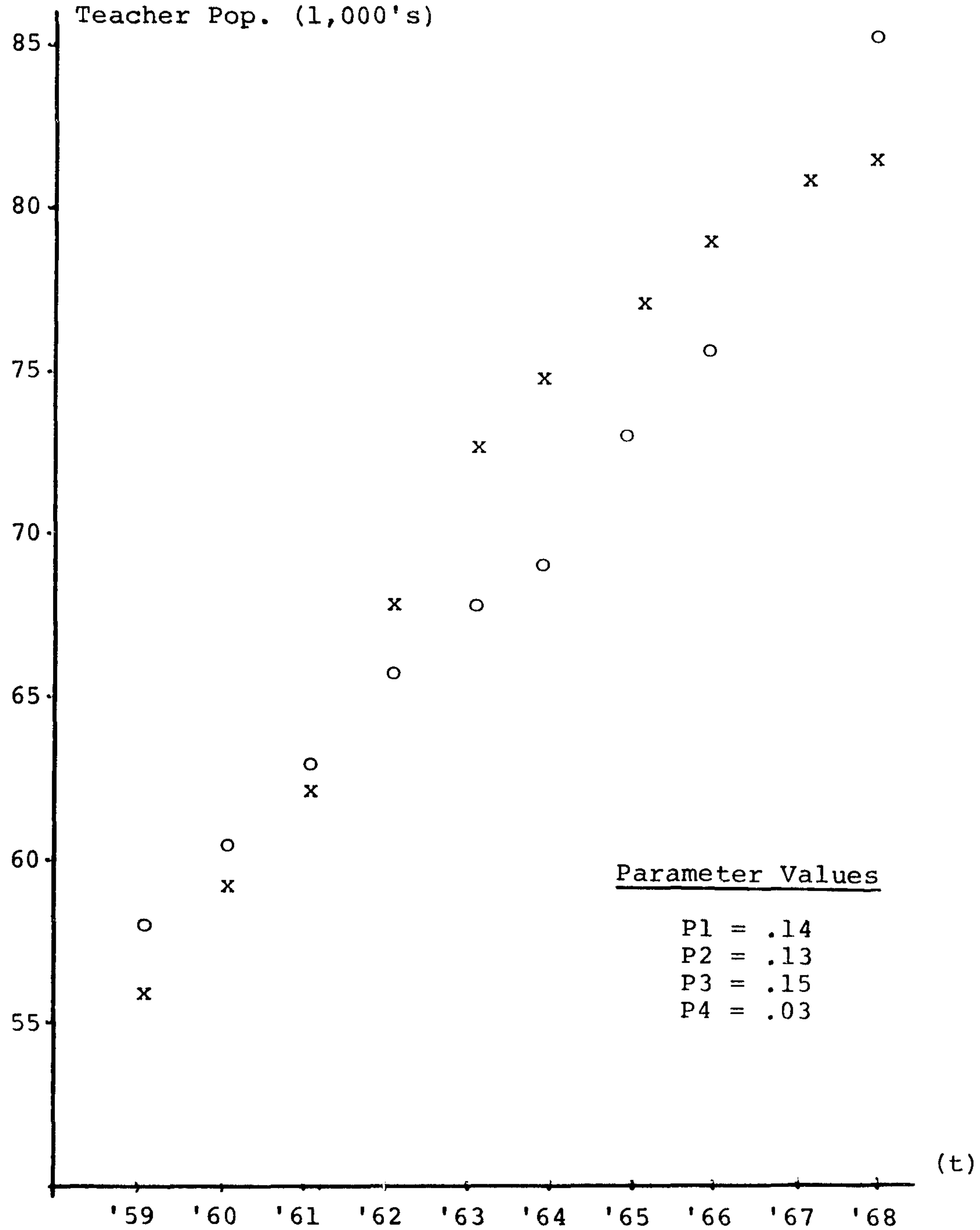

Figure 2. Comparison of actual and simulator predicted teacher populations (1959-1968).

Note: o Actual teacher populations.
x Simulation predictions of teacher populations-final run.

years (1959-1968). The observed mean was 75,540 for this simulated time series. Figure 2 is a comparison of the final-run of the simulation vehicle with population levels.

In summary, no previously specified value of Thiel's U statistic had been selected as the threshold of model acceptance. Instead, successive values of the statistic were employed to guide subsequent modifications of model parameters. It was planned that sensitivity analysis would terminate when time and resources dictated or when further adjustments achieved no improvement in performance of the model. The unexpectedly low values of Thiel's U contributed as much to the termination of sensitivity analysis as did the contraint of time. This prohibited a more complete exploration of the parameter space in search of a combination which would minimize the disparity between actual population levels and simulated levels.

In view of the extremely low value of Thiel's U (.023) and the relative agreement of the two time series in mean value, the performance of the model in relation to real world behavior was considered acceptable.

Model Experimentation

Experimentation with the simulation vehicle was planned to test the ability of the model to provide accurate planning estimates of the expected level of teacher employment over a ten year period (1959-1968). Two distinct experiments were planned and they are discussed separately in this section.

Experiment One

The first experiment was concerned with the accuracy of different methods for one year at a time forecasts. The experiment was planned as a maximum test of the accuracy of the simulation vehicle. That is, both the method of moving averages (2 years) and the method of exponential smoothing (α = .8) were given the required, annual update of true information necessary. The question was:

> Is there a difference between simulation forecasting and forecasting which employs either moving averages or exponential smoothing?

H_1: There is no difference between the method of forecasting by simulation or forecasting by moving averages or exponential smoothing.

H_2: There is a difference between the method of forecasting by simulation or forecasting by moving averages or exponential smoothing.

Results of the statistical analysis pertinent to the stated question are presented in Table 5.

Application of the F_{Max} test indicated that homogeneity of variances for forecasts existed for different forecasting methods. The mean square ratio for

TABLE 5.--Fixed Effects ANOVA for Teacher Population Predictions By Separate Forecasting Methods.

Source	SS	d.f.	MS	$F_{(.05)}$
Treatments	13,567,587	2	6,783,794	2.79
Error	65,701,139	27	2,433,375	. .
Total	79,268,726	29	. .	. .

treatments (2.79) did not exceed the tabled value of *F* at the .05 level of significance for 2 and 27 degrees of freedom respectively. The null hypothesis was retained and follow-up tests were not conducted. It can be tentatively assumed that there is no significant difference between accuracy of forecasts between different methods of forecasting.

Table 6 is a cell summary for the first experiment.

TABLE 6.--Cell Summary for Experiment One.

Types	N	Mean	Variance	Standard Deviation
Simulation	10	2,683	35,010,972	1,972
Moving Averages	10	4,328	16,993,614	1,374
Exponential Smoothing	10	3,575	13,696,552	1,233

Experiment Two

Experiment two was designed to test the accuracy of the simulation vehicle against both methods of moving averages and exponential smoothing given that ten years of planning data was desired. The conventional forecasting methods were not permitted a true information update (as would be the case if actual predictions were desired) but instead were modified by other means (see Chapter III) in order to achieve long range forecasts. The question was:

> For long range forecasts, is there a difference between simulation forecasting and forecasting which employs either a modified form of moving averages or a modified version of exponential smoothing?
>
> H_1: There is no difference between the method of forecasting by simulation or forecasting by modified versions of the method of moving averages or exponential smoothing.
>
> H_2: There is a difference between the method of forecasting by simulation or forecasting by modified versions of the method of moving averages or exponential smoothing.

Results of the statistical analysis pertinent to the above question are presented in Tables 7, 8, and 9.

Application of the F_{Max} test indicated that homogeneity of variances for predictions existed for different forecasting methods. The mean square ratio for treatments (9.85) exceeded the tabled value of F at the

.05 level of significance for 2 and 27 degrees of freedom respectively. The null hypothesis was rejected in favor of the alternative and follow-up tests were conducted.

Of the three pair-wise comparisons, two were found to be significant using the Scheffé procedure. The mean difference (2,683) for simulation forecasting was significantly smaller than the mean difference (8,309) for moving average predictions. Similarly, the mean difference for exponential smoothing (4,059) was significantly smaller than the mean difference (8,309) for moving averages. Significant differences between mean differences for simulation and for exponential smoothing did not exist.

These findings indicated that more accurate forecasts could be obtained by simulation and/or exponential smoothing than could be obtained by moving averages.

TABLE 7.--Fixed Effects ANOVA For Teacher Population Predictions By Separate Forecasting Methods.

Source	SS	d.f.	MS	$F_{(.05)}$
Treatments	172,052,177	2	86,026,088	9.85*
Error	235,889,300	27	8,736,640	. .
Total	407,941,477	29		

*Significant at $F_{(.05)(2,27)}$

Table 8 provides a cell summary for the second experiment.

TABLE 8.--Cell Summary for Experiment Two.

Types	N	Mean	Variance	Standard Deviation
Simulation	10	2,683	35,010,972	1,972
Moving Averages	10	8,309	166,030,791	4,295
Exponential Smoothing	10	4,059	34,847,536	1,967

Table 9 provides a summary of the follow-up tests for the second experiment.

TABLE 9.--Post-Hoc Comparisons for Experiment Two.

	Simulation	Moving Averages	Exponential Smoothing
Simulation		-5,627*	-1,376
Moving Averages			4,251*
Exponential Smoothing			

*Significant at the .05 level.

Summary

This chapter was concerned with three distinct parts of simulation research: model verification, model validation, and experimentation.

Model validation required an explanation of the simulation model accompanied by a rationale in support of design and structure. Acceptance of the model is heuristic and judgmental. That is, it remains for the observer to decide for himself, if the model is representative of the purported system of interest. This study, presented definitions of the elements of the model, specific examples of all functional relationships, and explanations to accompany each. Of particular importance to the process of validation is the necessity to understand the basic assumption upon which the model was constructed. That is, that students provide the primary demand for system resources. This assumption provided the functional basis for construction of the model.

Model verification required a two-phase, iterative procedure. The process of sensitivity analysis was employed to achieve successively better approximations of simulated performance. Thiel's U statistic was used as a guide to indicate when a particular modification of the model improved the performance. No a priori value of the statistic was specified as an acceptance threshold. The attained value of U (.02298) was the final congruence measure after numerous modifications and in terms of performance, the model was accepted.

Two questions were addressed in separate experiments and concerned the accuracy of simulation forecasting for short- and long-range planning purposes in comparison to the accuracy of conventional methods (moving averages and exponential smoothing). The null hypothesis was retained in the first experiment which was planned as a maximum test of the simulation vehicle. It was concluded that with regard to short-range planning all of the methods are equal in accuracy of forecasts. Differences in the means of each series of forecasts were noted and it was observed that simulation forecasts were more accurate.

In the second experiment the null hypothesis was rejected at the .05 level of significance. The F_{MAX} test indicated equality of variance among treatment methods and follow-up tests employing the Scheffé procedure were conducted which identified the nature of treatment differences. It was concluded that with regard to long-range planning simulation forecasts and predictions attained from a modified version of exponential smoothing were more accurate than predictions obtained from a modified version of the method of moving averages. Differences in the means of each prediction series were observed and simulation forecasts were observed to be more accurate.

CHAPTER V

SUMMARY AND CONCLUSIONS

This chapter provides summaries of the purpose of the study, the techniques and procedures employed, and the findings which concern model development, model validation, model verification, and experimentation. The last section is concerned with the conclusions from this study and suggested areas for future research.

Purpose of the Study

It was the purpose of this study to examine the student population and professional staff components of the public school system in the State of Michigan. Simulation was selected as the appropriate tool for wholistic analysis. The following objectives, evolved from the stated purpose of this study and provided guidance for the work:

1. Development of a simulation model.

2. Development of a functional computer program which embodied the simulation model.

3. Validation of the model.

4. Verification of the simulation model.

5. The completion of two experiments using the model to compare the accuracy of the simulation vehicle against conventional forecasting methods for the purpose of deriving short (one year) and long-range (ten year) planning information.

Given that the model could be developed, programmed, and successfully tested it was expected that the model would prove to be more accurate in forecasting future professional staff needs than conventional methods, such as, moving averages and exponential smoothing. In addition, it was believed that wholistic analysis followed by synthesis of system elements to form a mathematical model would provide greater insight regarding complex interactions within the public school system.

Techniques and Procedures

Data was accumulated for annual levels of two primary variables, student populations and teacher populations of the public school system in Michigan. A correlation coefficient ($r = .93$) was computed to provide an indication of the nature of the relationship between the two variables. Since each component comprised a population sub-system, additional system elements were identified using a scheme suggested by Blalock (1968).

Additional data for these elements (births, in/out migration, attrition) were located. Then, a mathematical model of the system as identified was constructed and a computer program was written representing the model of the system.

Model validation followed and entailed a three part procedure. First, all elements of the simulation model were defined. Second, the elements were presented as related by operating characteristics of the system and the supply-demand function which unites the student population component with the professional staff component. A discussion of the functional relationships in terms of the real world system of interest accompanied the explanation of the mathematical model. Third, eight questions (which had been previously formulated) regarding the nature of the model were presented and answered.

Procedures employed in model verification were based on an iterative scheme. Sensitivity analysis and Thiel's U statistic were alternately employed to achieve successively better approximations to the final system. The model was accepted when Thiel's U statistic reached .023 for a comparison of the simulator generated endogenous variable TPOP(t) with the corresponding time series of actual values. The foregoing procedure constituted verification of the model as opposed to selection of an a priori value of the U statistic as the acceptance threshold.

Finally, two experiments were planned and conducted which compared the accuracy of simulation forecasting with the method of moving averages (two years) and exponential smoothing ($\alpha = .8$). The design of both experiments was similar. A fixed effects, analysis of variance was employed to test the hypothesis of equal forecasting accuracy between all methods. A test of the hypothesis of homogeneity of variance was planned for each experiment. It was further planned that if the null hypothesis was rejected the F_{MAX} test would be followed by post hoc comparisons using the Scheffé procedure.

The first experiment was planned as a test of the relative accuracy of each of the methods for short-range planning, i.e., year-to-year forecasts. The second experiment was planned as a test of the relative accuracy of each of the methods for long-range planning, i.e., ten year forecasts.

Analysis of Findings

Model validation attempted to demonstrate and explain elements of the model and wholistic representation in terms of real world components. Acceptance of the model as being representative of the real world was a judgmental decision. Of particular important to validation in this study, is the basic assumption that student population levels drive the system. That is, public school students present a primary demand for system resources.

This assumption provided the foundation for construction of the model and is the method by which the concept of "stress" from general systems theory was operationalized. Model validation is necessarily heuristic and judgmental but has been called for by authorities in the field as being an important component of simulation research.

Model verification entailed a decision to accept or reject the model on the basis of performance, i.e., the ability of the model to approximate real world systemic behavior. Thiel's U statistic was employed as the decision criterion. The performance of the model, as measured by a simulated time series for the primary endogenous variable representing professional staff levels over time, was accepted after successive parameter modifications that finally yielded U = .023.

Two questions were addressed in separate experiments and concerned the accuracy of simulation forecasting for short- and long-range planning purposes in comparison with the method of moving averages and exponential smoothing. All statistical tests were conducted employing an alpha level of .05.

The first experiment was a test of the forecasting ability of three methods (simulation, moving averages, and exponential smoothing) for short-range (year-to-year) planning. The null hypothesis of no differences between treatments was retained (mean square ratio = 2.79). A test of the equality of variances resulted in retention of the null hypothesis and indicated the assumption of homogeneity of variance was valid. The results of the analysis were interpreted to mean that for the purposes of short-range, year-to-year planning either of the three methods would product forecasts whose accuracy in relation to the other two methods were about equal. It is interesting to note, however, that differences in the means, were observed and that the mean of simulation forecasts (69,729) was considerably nearer the mean of the actual time series (70,038), then were the means of the two conventional methods (65,710 and 66,463 respectively).

The second experiment was a test of the forecasting ability of three methods (simulation and modified versions of moving averages and exponential smoothing) for long-range (ten years) planning needs. The null hypothesis of no differences between means was rejected (mean square ratio = 9.85) in favor of the alternate. Subsequent pairwise mean comparisons indicated that simulation forecasts were significantly more accurate than those attained by the method of moving averages and that exponential smoothing forecasts were significantly more accurate than moving average forecasts. Significant differences were not found between simulation forecasts and exponential smoothing though once again differences were observed and simulation forecasts were observed to be more accurate.

Conclusions

The following conclusions are derived from the findings of this investigation:

1. It is possible to develop a valid simulation model which is representative of the public school system in the State of Michigan (realization of the first and fourth objectives). Further, it is believed that the model as constructed is generalizable to local school districts as well as to other state systems if parameter values are adjusted to reflect local conditions.

2. The simulation model can be embodied in a computer program and satisfactory response of the model in terms of functional performance of primary endogenous variables was realized (completion of the second and third objectives).

3. Future resource (professional staff) needs for short-range planning purposes derived from the model are not significantly different than forecasts obtained by the methods of moving averages and exponential smoothing when the conventional methods are given a true information update each year. However, aside from this finding,

differences in the means were observed and the mean of predictions obtained from the simulation vehicle (69,729) was noticeably more accurate than the means of predictions obtained by the conventional methods (65,710 and 66,463 respectively) in comparison to the mean of the real world time series (70,038). Standard deviations for each method were 1,972, 1,374, 1,233 respectively.

4. Future resource (professional staff) needs for long-range planning purposes derived from the model were significantly more accurate than those obtained by the method of moving averages. Of the three pairwise comparisons two were significant. Both simulation and exponential smoothing forecasts were significantly different from moving averages which was least accurate. There was no significant difference between simulation predictions and forecasts attained by exponential smoothing. That is, given the modification of exponential smoothing that was employed, either method is just as accurate as the other. However, observation of the mean of predictions by each method indicated once again that simulation was observably more accurate.

Implications of the Study

1. Simulation is a viable tool of analysis insofar as investigation of complex organizational systems on a wholistic basis is the concern. Simulation permits functional integration of numerous, empirically derived, systemic variables and provides unlimited opportunity for process analysis all of which contributes to enlightened understanding of the dynamics of the real world system of interest.

2. The concept of "stress" when operationalized as a systemic demand and represented by the number of public school students requiring system resources (professional staff) provides an important foundation for construction and development of simulation models.

3. The supply-demand function is a viable means of representing inter-component interaction within the overall organizational process. That is, all sub-systems of the organization are conceptualized as "open systems" with identifiable "boundaries." As such, the sub-systems (student sector, staff sector) compete for organizational resources (staff services, money, materials) as required inputs to the sector. There appear to be at least two sources of stress or demand. As used

in this study, demand was a variable which originated from a source external to the system, that is, student population levels are a function of external parameters. It seems reasonable to assume that stress in the form of interaction demands could just as reasonably originate from within the system, from internal sources. Equilibrium, then could be operationalized as a function of the totality of stress interactions over time. In this respect, the supply-demand function is useful as a way of depicting the dynamics of "boundary exchange" either internally, between components, or externally as between the system and ancillary systems or between the system and a supra-system. Thus, the demand for trained professionals appears to be a function of several intra-component variables such as attrition, the inactive pool, and the deployment of staff resources. The model further suggests that the demand for trained staff transcends variables peculiar to the professional staff component and is in fact traceable to the levels of students requiring services and to the number of births.

4. The inclusion of time as a basic parameter of the simulation model in conjunction with the previously mentioned supply-demand relationship permits

accurate prediction of professional staff needs at least five years in advance of need. Such predictions provide sufficient lead-time to be used as a guide for institutional production. The net replacement estimate (6.5%) or about 5,000 teachers per year in comparison with current production rates (estimated at approximately 17,000 annually inflated by net in/out migration of approximately 4,500 entering teachers per year) results in an estimated over-production of about 16,000 teachers per year.

The implication for higher education may be a review of goal primacy and serious consideration of expanded services to currently employed professionals as opposed to continued production of new professionals.

5. The simulation model provides a viable foundation for at least one component of a management information system. Such systems are presently under pilot study in several states as a result of recent contracts awarded by the United States Office of Education.

Suggestions for Future Research

The simulation vehicle developed in this study represents only two components of the public school system in Michigan and is founded on the assumption that the number of clients to be served (students) represents a primary drive for the system. However, within these limitations there are virtually an unlimited number of possible directions for future research. A limited number of suggestions are provided and incorporate a suggested order of priority.

1. The present study could not complete the professional staff sector because of a lack of data for important variables, the inactive pool and available staff. Completion of this component of the model and testing of all endogenous variables by Thiel's U statistic or a more appropriate congruence measure is a first order need.

2. The present study did not systematically explore all possible parameter magnitudes within specified limits. Thus, a different combination of parameter values might provide more accurate predictions.

3. The model should be expanded to provide for inclusion of other system components such as the physical facilities or financial resources sectors. These have been included in the schematic of the system (see Appendix B) but could not be accommodated by the present study.

4. Experiments should be designed to test the present means of parameter estimation against results that could be obtained if the parameters were represented by functions which could more appropriately describe the effects of system parameters over time.

5. Exogenous variables such as Birth(t) ought to be represented stochastically to examine the functional limits of the system under various hypothesized stress forces. How long, for example, does it require for institutional production to recover from or respond to varying rates of birth demand? Or, what rate of increase of births over time is required to exceed the recovery capability of both the inactive pool, InPool(t), and institutional production, InProd(t)?

6. Given that the model is both expanded and tested for functional limitations (not a mandatory but a preferential condition) experiments may be designed to test the effects of alternative policies on the system. Thus, one might explore the effects of different staffing patterns as an internal demand for professional staff resources. Or, one might examine the effect of new certification rules which would restrict or increase the supply of professional staff. Finally, one might be

motivated to study the effect of policies which would limit the production rates of trained staff by institutions of higher education.

7. Finally, it is possible to envision a time in the near future when one simulation model will be joined with others to facilitate representation of systems of systems whose complexity and magnitude may approach that of the real world. One can anticipate that understanding may be sacrificed for greatly enhanced prediction.

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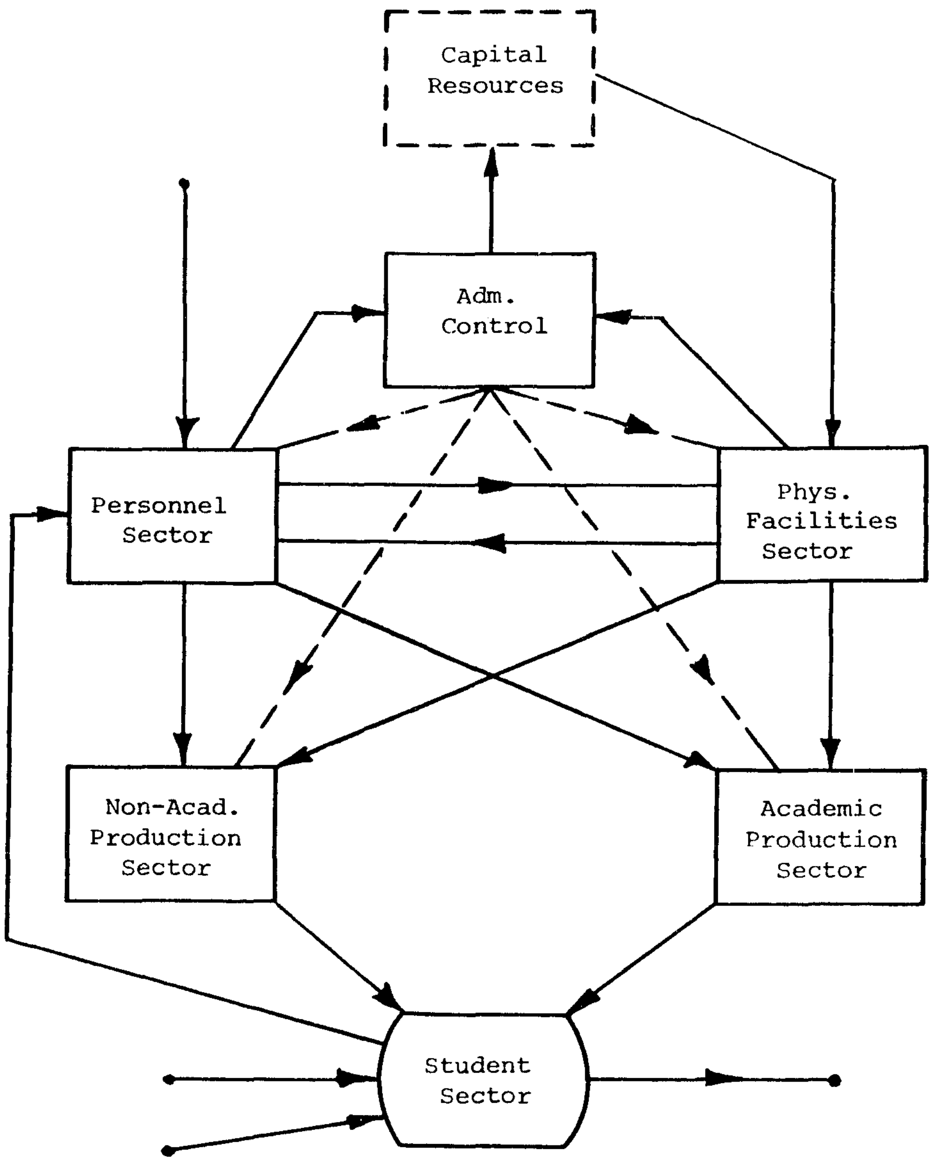
APPENDICES

APPENDIX A

THE MSU UNIVERSITY MODEL

The Koenig Model (MSU-SIM)



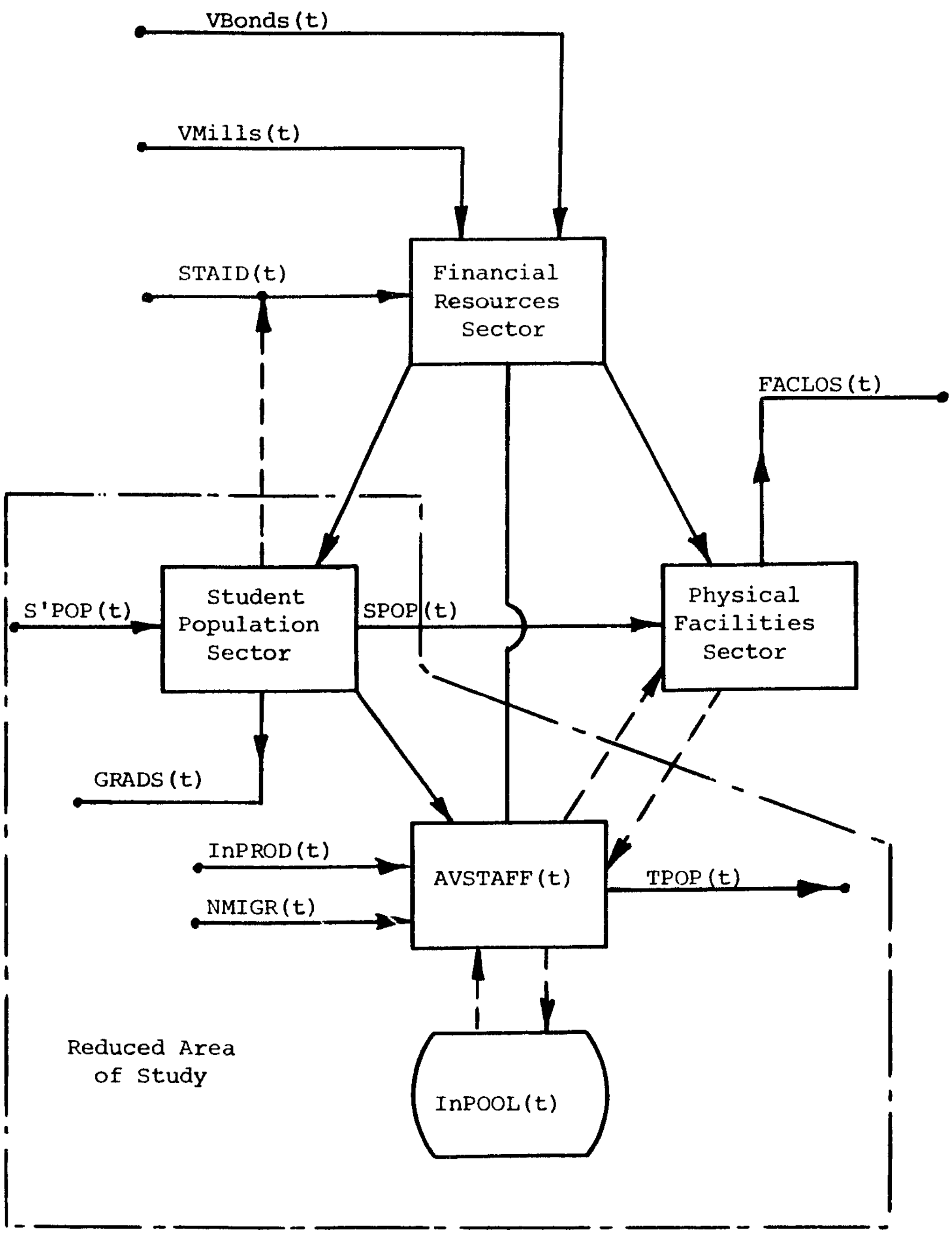
Source: Koenig, et al., 1968, p. 21.

APPENDIX B

MICHIGAN PUBLIC SCHOOL SYSTEM

SIMULATION MODEL SCHEMATIC

Modified Version of the Koenig Model
Michigan Public School System Schematic



APPENDIX C

MICHIGAN BIRTH RATES 1940-1971

TABLE C-1.--Michigan Birth Rates (1940-1971).

Year	Births	Year	Births
1940	99,106	1956	206,068
1941	107,498	1957	208,488
1942	124,068	1958	202,690
1943	125,441	1959	198,301
1944	113,586	1960	195,056
1945	111,557	1961	192,825
1946	138,572	1962	182,790
1947	160,275	1963	178,871
1948	153,726	1964	175,103
1949	156,469	1965	166,464
1950	160,055	1966	165,794
1951	172,451	1967	162,756
1952	177,835	1968	159,058
1953	182,968	1969	163,811
1954	192,104	1970	170,546
1955	196,294	1971	161,163

Source: Department of Public Health, Michigan.

TABLE C-2.--Age-Specific Death Rate Per 1,000 Individuals.

Age	Rate/1,000	Age	Rate/1,000
0	7.08	10	1.21
1	1.76	11	1.23
2	1.52	12	1.26
3	1.46	13	1.32
4	1.40	14	1.39
5	1.35	15	1.46
6	1.30	16	1.54
7	1.26	17	1.62
8	1.23	18	1.69
9	1.21	19	1.74

Source: Commissioners Standard Mortality Table, 1958.

APPENDIX D

EDUSIM--COMPUTER PROGRAM

EDUSIM

```
PRØGRAM EDUSIM(INPUT,ØUTPUT)
DIMENSIØN TBL(21,50),DTH(20),SCHL(50)
DIMENSIØN TPØP(50),NSTAFF(50),ELMSTF(50),SECSTF(50)
DATA DTH/7.08,1.76,1.52,1.46,1.40,1.35,1.30,1.26,1.23,1.21,
+1.21,1.23,1.26,1.32,1.39,1.46,1.54,1.62,1.69,1.74/
READ 100,IBASE,N
100 FØRMAT(I4,I2)
READ 101,(TBL(1,I),I=1,N)
101 FØRMAT(10F6.0)
C
C PARAMETER INITIALIZATIØN PHASE
C
P1=.14
P2=.13
P3=.15
P4=.036
P5=.065
P6=.485
P7=.515
C
C BUILD THE MATRIX ØF SURVIVØR PØPULATIØNS
C
DØ 1 J=1,N
DØ 1 K=2,21
IND=K-1
TBL(K,J)=TBL(IND,J)-((TBL(IND,J)/1000)*DTH(IND))
1 CØNTINUE
C
C GENERATE SIMULATED SPØP(T)=SCHL(J) AND TPØP FØR 1957 TØ 1975

C
IK=N-13
DØ 2 J=1,IK
SCHL(J)=)
II=J+12
DØ 3 K=J,II
I=20-K
3 SCHL(J)=SCHL(J)+TBL(I,K)
SCHL(J)=SCHL(J)+(P1*SCHL(J))-(P2*SCHL(J))-(P3*SCHL(J))
TPØP(J) =P4*SCHL(J)
AVSTF(t)=INPROD(t)+INPOOL(t)-ATTR(t)+NMIGR(t)+TPØP(t)
NSTAFF(J)=P5*TPØP(J)
ELMSTF(J)=P6*NSTAFF(J)
SECSTF(J)=P7*NSTAFF(J)
2 CØNTINUE
IBASE =IBASE+17
DØ 4 J=1,IK
PRINT 102,IBASE,SCHL(J),TPØP(J),NSTAFF(J),ELMSTF(J),SECSTF(J)

102 FØRMAT(*0*,I4,F13.2,4F10.2)
4 IBASE=IBASE+1
CALL EXIT
END
```

APPENDIX E

CERTIFICATE DISTRIBUTION FOR 1968

TABLE E-1.--Certificate Distribution for Reported 1968 Professional Staff in Michigan.

Certificate Type	Number	Percent
Elementary Provisional	15,657	18.45
Elementary Permanent	16,706	19.71
Secondary Provisional	17,279	20.39
Secondary Permanent	17,602	20.77
Life	10,304	12.16
Full Year Permit	4,702	5.55
State Limited	176	.21
County Limited	166	.20
Provisional or Permanent Not Required	2,110	2.49
Certificate Not Required	57	.07
Total	84,759	100.00

Source: MSDE Personnel Report, 1968.