DOCUMENT RESUME

ED 030 399 HE 000 985

By-Smith, Lester Sanford
Computer Simulation Models of Economic Systems in Higher Education.
Ohio State Univ., Columbus.
Pub Date 69
Note-74p.
EDRS Price MF-$0.50 HC-$3.80
Descriptors-*Administration, Budgeting, Computer Programs, *Higher Education, *Models, *Program Budgeting, Resource Allocations, *Simulators, Systems Approach

The increasing complexity of educational operations make analytical tools, such as computer simulation models, especially desirable for educational administrators. This MA thesis examined the feasibility of developing computer simulation models of economic systems in higher education to assist decision makers in allocating resources. The report discusses: the relationship of the systems approach to the decision making process; the design of computer simulation models; and the development of a model consisting of mathematical equations and logical flow charts to depict an economic system in a university department. Since the model can be used to establish costs for programs in a department, it should become an integral part of a program budget analysis. Although the writing of a computer program and validation of the model have yet to be accomplished, the project was successful in designing a significant administrative tool. (JS)

COMPUTER SIMULATION MODELS OF ECONOMIC SYSTEMS IN HIGHER EDUCATION

A Thesis

Presented in Partial Fulfillment of the Requirements

for the Degree Master of Arts

by

Lester Sanford Smith, A.B.

The Ohio State University

1969

Approved by

Adviser
Department of Education

TABLE OF CONTENTS

Acknowledgments

I wish to express my gratitude to Dr. Desmond L. Cook, my adviser, for his encouragement and assistance in the formulation and preparation of this thesis.

I am also grateful to Dr. Donald P. Anderson for his careful reading of the manuscript and serving on my examining committee.

My sincere thanks to Mrs. Barbara Chrissinger for enduring my poor handwriting and for typing the many revisions needed to complete my work.

Finally, a special tribute to my wife, Martha Jean, and to my son, Doug, for their patience, understanding, and love.

LIST OF ILLUSTRATIONS

CHAPTER ONE

INTRODUCTION

The advent of high-speed digital computers in the early 1950's precipitated the sophistication of various new analytical tools as an aid to decision-making. A special class of these analytical tools, known as computer simulation models, has had a significant impact on a number of disciplines. Applications of computer simulation models have been described in the literature and include such fields as medicine, physics, engineering, space technology, social sciences, business administration, and economics to mention only a few.[1]

Administrators of higher education can benefit from the potentiality of these newly emerging methods for coping with problems of efficiency and economy in the educational system. Increasingly, decision makers in colleges and universities have need for up-to-the-minute, accurate data and information concerning the complex activities of their organization. Unfortunately, the National Science Foundation's report on Systems for Measuring

---

[1]Thomas H. Naylor, et. al., Computer Simulation Techniques (New York: John Wiley & Sons, Inc., 1966), p. VII.

<u>and Reporting the Resources and Activities of Colleges and Universities</u> points out that:

> At the present time, however, the measuring, recording, and reporting of these data are in a state of confusion. . . .In short, experience shows that more systematic and uniform mechanisms must be adopted if colleges and universities are to be able to record and report their activities accurately and completely with a reasonable expenditure of time and money.[2]

Computer simulation modeling, one of the newly emerging analytical techniques for dealing with complex problems, may provide the needed mechanism.

<u>Purpose</u>

The purpose of this investigation is to examine the feasibility of developing computer simulation models of economic systems in higher education to assist decision-makers in allocating resources.

<u>Design of the study</u>

The study is designed to lead to the formulation of hypotheses which provide a basis for more empirical research. The present investigation, therefore, is a preliminary step toward

---

[2] National Science Foundation, <u>Systems for Measuring and Reporting the Resources and Activities of Colleges and Universities</u> (NSF 67-15. Washington, D.C.: National Science Foundation, 1967), p. 4-5.

further research. As such, the study looks at computer simulation models as administrative tools. The intent is to develop a model which will describe fluctuations in the resource requirements of an academic department with more accurate and rapid methods than are presently available. The model should show the effect various changes to inputs and parameters will have on the resource requirements of a department. The model will not describe any change in quality from varying inputs or parameters. The decision maker must evaluate the alternatives by using subjective opinions of the intangible factors which, in the case of academic matters, would be academic quality.

Definition of terms

Simulation, in a broad sense, is the construction and use of a "model" whether symbolic (pictorial, verbal, mathematical) or physical. In a more specific meaning related to research and teaching, simulation is the building of an individual or group process and experimenting on this replication by manipulating its variables and their interrelationships.[3] More precisely for the purposes of this study:

---

[3] Harold Guetzkow (ed.), Simulation in Social Science: Readings (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1962), p. 3.

> Simulation is a numerical technique for conducting experiments on a digital computer, which involves certain types of mathematical and logical models that describe the behavior of a business or economic system (or some component thereof) over extended periods of real time.[4]

Mathematical models of economic systems consist of four well defined elements: components, variables, parameters and functional relationships. Components are the items dealt with in the simulation model. Attributes or properties of the components are called variables. Parameters are regression coefficients or probability values which provide the substance for a particular system. Functional relationships are expressions of how the variables interact with one another when the simulated system operates. A mathematical model of a system is actually a set of equations whose solution explains or predicts changes in the state of the system. The use of a mathematical model is a consequence of analytical efforts to abstract and describe the real world.[5]

Computer models are simply defined as mathematical models expressed or written according to a particular set of rules so that

---

[4]Naylor, op. cit., p. 3.

[5]Claude McMillan and Richard F. Gonzalez, Systems Analysis: A Computer Approach to Decision Models (revised edition; Homewood, Illinois: Richard D. Irwin, Inc., 1968), p. 11.

the model may be processed by the computer. Computers understand only one language which is called machine language. Developing fluency in machine language is difficult. Fortunately, less difficult (higher-order) languages such as FORTRAN (an abbreviation for FORmula TRANslation) are rather universally available.

Simulation models are arbitrarily classified as determinists, stochastic, or expected value. Deterministic models have unique outcomes for a given set of inputs. In stochastic models, outputs for a given set of inputs can be predicted only in a probabilistic context. The functional relationships depend on chance parameters. In expected value models, mean values are assigned to the chance parameters. A simulation model may contain all or any features of deterministic, stochastic, or expected value models.[6]

Assumptions

Three basic assumptions were followed that led to the final departmental functions included in the model.

1. The model should focus on one of the primary concerns of administrators in higher education. This has been assumed to

---

Francis F. Martin, Computer Modeling and Simulation (New York: John Wiley & Sons, Inc., 1968), p. 5.

be the identification of needs and the allocation of limited resources.

2. It is assumed that a basic unit of organization in a university is a department. A department can be subdivided into an identifiable group of programs that demand quantifiable resources to produce specific output.

3. An initial simulation model should depict activities at the microanalytic level. The components have been identified as the people, space, and money needed to support a program. Linear equations are used for aggregating products of conversion ratios and such things as the number and type of people, square feet of space and dollar cost associated with programs in a department.

Constraints

The types of functions chosen for the model were selected because they represent the basic demand imposed on the system. The utilization of the basic resources available to the system expresses interdepartmental relationships. Two constraints on the choice of simulated functions ensued.

1. The primary intent in constructing this model is to provide an instrument for short-range and long-range planning.

Formulation of the problem has been directed toward identifying the resource requirements of educational programs to assist decision makers in the allocative process.

2. The data available for parameter estimation is a necessary guide in the selection of simulated functions. A model expressed in a form for which no parameters can be derived would be useless. Therefore, an effort has been made in selecting simulated functions to cast them in a form for which existing records at the Ohio State University can be used to estimate parameters.

Delimitation

The procedure for the investigation may be specified in terms of the following list of nine elements involved in planning computer simulation experiments:

1. Formulation of the problem.
2. Collection and processing of real world data.
3. Formulation of mathematical model.
4. Estimation of parameters of operating characteristics from real world data.
5. Evaluation of the model and parameter estimates.
6. Formulation of a computer program.
7. Validation.
8. Design of simulation experiments.
9. Analysis of simulation data.[7]

[7] Naylor, op. cit., p. 23.

The flow chart presented in Figure 1, outlines this procedure. Emphasis of the present project is only on item 3, the development of a mathematical model for simulating economic systems of an academic unit in higher education.

The estimation of parameters (item 4) was performed for only limited functions to illustrate the application of the model. Limiting the estimation of parameters prevented a complete evaluation of the model (item 5) as a simulation of an academic unit. A refining process needs to be repeated until a satisfactory model is developed. The model developed in this research project is the first approximation, formulated as a basis for iterations of the process depicted in items 1 through 5 above.

Items 6 through 9 are not included in the study because the process would involve an extensive research effort quite beyond the scope of this project.

Organization of the report

The present chapter presented the purpose and design of the study, a definition of terms, necessary assumptions and constraints, and a delimitation of the investigation.

Chapter II describes the systems approach and the decision making process as significant concepts in the development

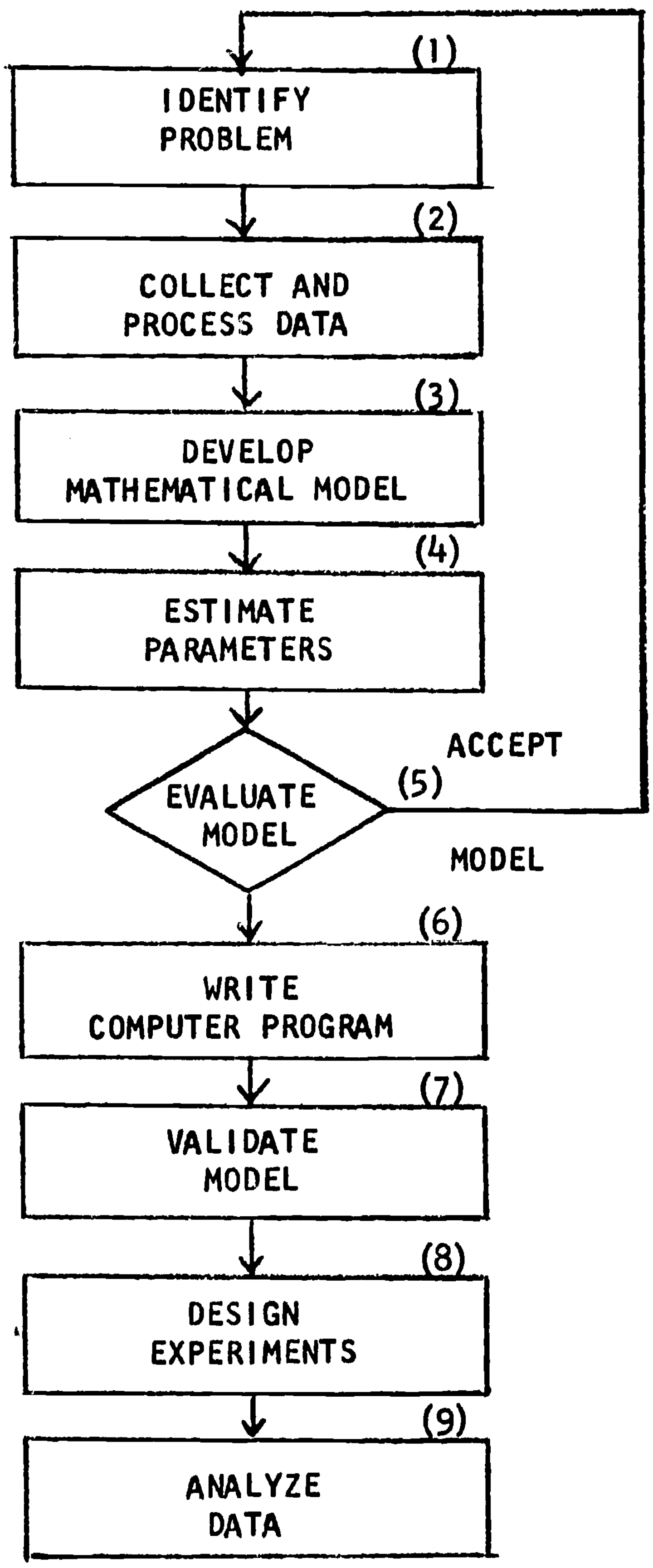

FIGURE 1. FLOW CHART FOR PLANNING SIMULATION EXPERIMENTS

(after Naylor *et al.*)

of computer simulation models.

Chapter III discusses the design of computer simulation models. This includes describing the several types of computer simulation models, classification of model elements, and procedures for developing the models.

Chapter IV is an effort to develop a computer simulation model of an economic system in higher education. A general description of the model is followed by an explication of mathematical equations and logical flow charts.

Chapter V contains conclusions regarding the results of this research project and recommendations for further work to be done.

CHAPTER TWO

SYSTEMS APPROACH AND THE DECISION MAKING PROCESS

This chapter presents a discussion of the systems approach since it plays such an important role in the development of computer simulation models. The word "system" is a very old one. It has been used for many years in everyday language by both laymen and specialists. Warren E. Alberts responded in answer to the question, "What is a system?": "As you can probably guess, a system is anything you want it to be."[8] Timms described a system as "a set of elements so interrelated and integrated that the whole displays unique attributes."[9] More precisely, Johnson, Kast and Rosenzweig define a system as "an array of components designed to accomplish a particular objective according to plan."[10]

---

[8] Report of System Simulation Symposium (New York: American Institute of Instructional Engineers, May 16, 17, 1957), quoted in Howard L. Timms, Introduction to Operations Management (Homewood, Illinois: Richard D. Irwin, Inc., 1967), p. 83.

[9] Howard L. Timms, Introduction to Operations Management (Homewood, Illinois: Richard D. Irwin, Inc., 1967), p. 84.

[10] Richard A. Johnson, Fremont E. Kast, and James E. Rosenzaeig, The Theory and Management of Systems (second edition; New York: McGraw-Hill Book Company, Inc., 1967), p. 113.

Three significant points are implied in this last definition: (1) there must be a purpose or objective which the system is designed to perform, (2) there must be a plan, or an established arrangement of the components to produce a desired goal, and (3) there must be inputs of resources (people, space, money, etc.) which are allocated according to the predetermined plan.

A basic system is illustrated in Figure 2. Input resources are allocated according to a plan. A processor converts the input into products or services. Output is measured and feedback modifies the plan. A system can be viewed as a self-contained unit that contains both input and output. The process of converting the input into products or services is in a constant state of flux. The system must be continuously maintained or revised.

The "universe" is a system. Within this system are all sorts of interrelated subsystems broadly classified as either natural or man-made. Natural subsystems include the galaxies, of which our solar system is a part or subsystem. The solar system, in turn, includes various planetary subsystems such as the earth. Man is a natural biological system with skeletal, organic and muscle subsystems, all highly interrelated to form an integrated whole.

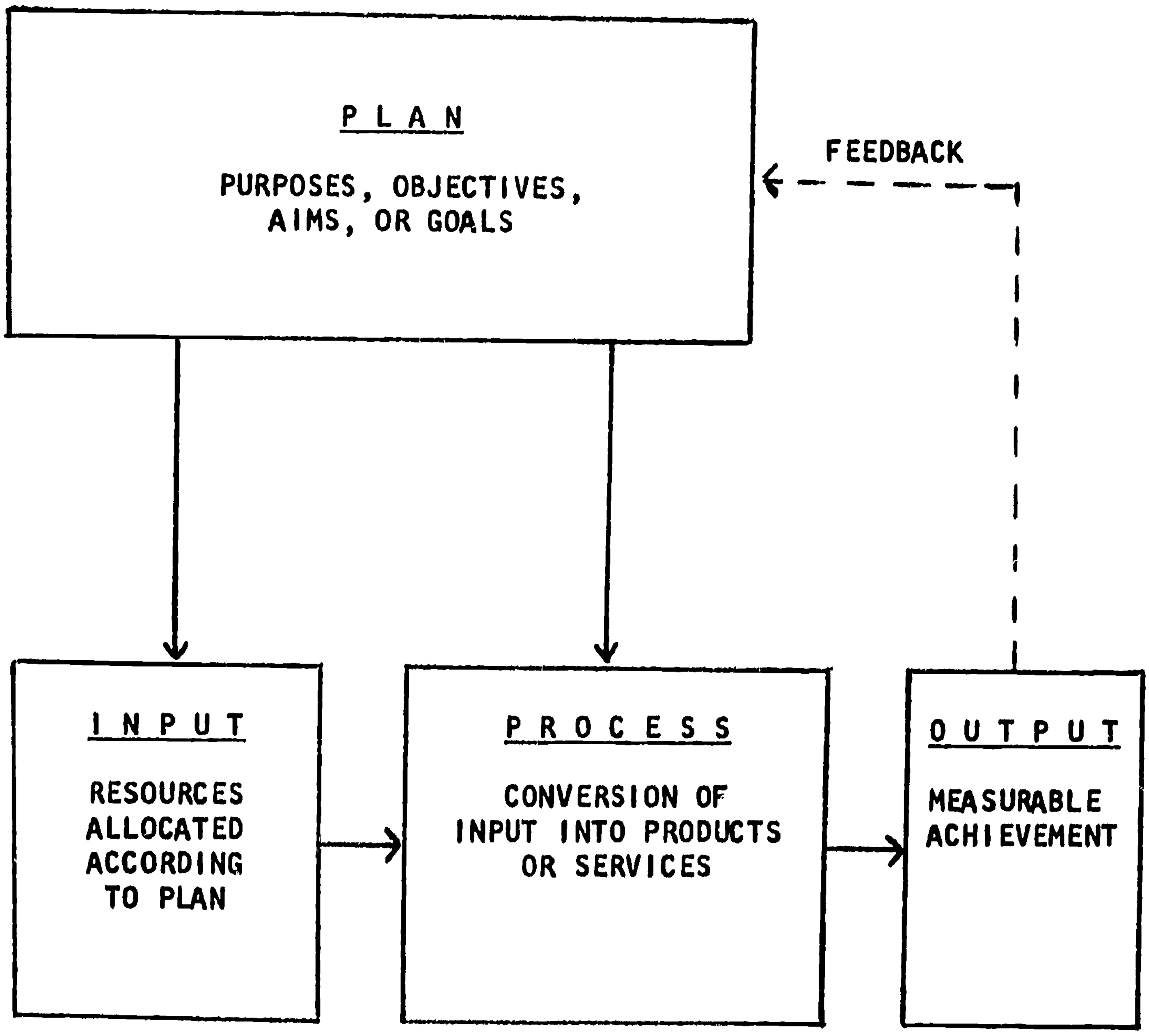

FIGURE 2. A BASIC SYSTEM

Man-made systems may be either social or economic. These systems are not well understood and have generally developed without any real planning. Recent efforts to improve our economic system, while successful to a degree, "disclose that, while we know a lot about it, we do not fully understand all the complex interrelationships of a high-level dynamic economy."[11]

There are systems within systems, within systems. Each system is a subsystem of a higher order system. At the same time, each system has its own interrelated elements that themselves may be subsystems. Obviously, then, there is a hierarchy of systems. To decide when one is dealing with a system or a subsystem depends upon the point of view and the purpose behind the inquiry.

When we know enough about a system, whether it be physical, biological, informational, or functional, we can develop a model that represents that system. The model can then be utilized to learn more about the operation of the system as a whole than we could before the model was constructed. Manipulating parameters, variables or constraints as alternatives within

[11] Timms, op. cit., p. 85

the model can "simulate" a variety of ways in which the actual system might be caused to operate. This exercising a model of a system is called a simulation experiment. It can be accomplished "by hand" or by computer, depending upon the complexity of the model and the degree of manipulation desired.

THE SYSTEMS APPROACH

The systems approach is not a set, established process with clear-cut rules to follow. It is primarily a way of thinking which "provides a framework for visualizing internal and external environmental factors as an integrated whole."[12] This allows for subsystems, as well as the complex super-systems within which members of organizations must operate. The systems approach fosters a way of thinking which helps to dissolve some of the complexity of problems and yet helps to recognize the nature of complex problems so that we may operate within the perceived environment.

Pfeiffer views the systems approach as a team effort.

> The systems approach can be regarded as a disciplined way of using specialists in a variety of fields to analyze as precisely as

---

[12]Johnson, op. cit., p. 3.

> possible, sets of activities whose interrelationships are very complicated, and of formulating comprehensive and flexible plans on the basis of the analysis.[13]

The basic effort is to reconcile objectives and resources, to achieve clearly specified compromises between what we want and what we expect to get. Clearly, the emphasis is to provide the means for helping people make decisions.

The systems approach concerns itself with the nature of decision making. At the moment of decision, when a decision maker must select one course of action over another, no one can help him. Man has always had to deal with intangibles and for this task there is no acceptable substitute for judgment. The systems approach, however, can provide assistance before the decision maker reaches the decision point. Reliable information combined with judgment in using analysis based on advanced technology can be more effective than either alone.

The power of the systems approach is that it offers a solid objective formulation for decisions. When policies and recommendations are to be justified, the administrator will find

---

[13]John Pfeiffer, New Look at Education: Systems Analysis in our Schools and Colleges (New York: The Odyssey Press, 1968), p. 2.

the systems approach to be especially useful. He will be better able to state a case with confidence when called upon to account for his plans or to substantiate his complaints about limited resources. He will be in a better position to more effectively control the future of the organization for which he is responsible.

THE DECISION MAKING PROCESS

Decision makers face difficult choices from among competing alternatives. Recent refinements in analytical techniques provide better ways to look at complex problems of choice and to identify a preferred choice. In an educational context, typical analyses of choice deal with such questions as whether additional course sections should be opened; should new faculty be hired and at what rank; whether to train more science teachers or guidance specialists; or whether to increase the number of student teachers in the inner city program and, if so, when and how many. Each such analysis involves at some point a comparison of alternative courses of action in terms of their costs and their probability for achieving some specific objective. Usually, the analyst attempts to minimize cost subject to some program requirement or, conversely, to maximize some physical measure of output subject to a budget constraint. Other facets of the analysis, however, may be of greater significance such as the specification of the right objectives, the determination of a satisfactory way to measure performance, or the discovery of better alternatives.

The systems approach to a complete analysis of choice includes a look at the entire problem in its proper context. The essence of the approach is to construct and operate within an abstract representation or model of a situation appropriate to the problem. The significance of the model in the process of comparing alternatives is more apparent when we look at its relation to the other elements of the process. In every analysis of choice, Quade suggests there are five primary elements: objectives, alternatives, costs, models, and criterion.[14]

Objectives

The decision-maker's objectives must be clearly defined before any course of action can be considered. For example, how many courses are to be taught, degrees granted, books published or services performed. After the objectives have been identified, some means must be established for measuring the extent to which

---

[14] E. S. Quade and W. I. Boucher, Systems Analysis and Policy Planning: Applications in Defense (New York: American Elsevier Publishing Company, Inc., 1968), p. 12.

these objectives are attained. Then, and only then, can the possible actions be examined, compared, and chosen. The choice should be based on how effectively and at what cost the preffered action will accomplish these objectives.

Alternatives

The various alternatives are the means by which the objectives can hopefully be attained. They may be specific activities, strategies, or policies and need not be substitutes for each other or perform the same functions. For example, changing faculty-student ratio, purchasing more equipment, or increasing faculty salaries may each be an alternative for improving the quality or quantity of output.

Costs

When a particular alternative is selected for accomplishing the program's objectives, certain specific resources can no longer be used for other purposes. Resources may include personnel, money, or facilities. These represent the costs for that alternative. Most costs can be measured in terms of money, but for a future period of time, the true measure of cost should be in terms of the opportunities they preclude. For example, if an objective of the College of Education is to train teachers for inner-city schools, the irritations and inconveniences caused to suburban schools must be considered as costs since the teacher training capability of the College may be diverted from the regular programs and thus create an acute shortage of teachers for the suburban schools.

Models

A model is a simplified representation of the real world that abstracts only those factors thought to be essential to the situation studied. Factors considered as having little influence can be assumed away. By developing a set of reasonable assumptions, we can reduce a highly complex situation to a manageable one. The representation may range from a purely verbal description of the situation in which intuition alone is used to predict the consequences of various choices, to an extremely precise set of mathematical equations programmed for solution on a high-speed electronic computer.

Criterion

A criterion is a rule or standard by which alternatives are ranked in order of desirability or selected from among the most promising. It may be considered an "indicator" which can be related to the objectives and provide assistance in measuring how well the objectives are being achieved. In other words, the criterion provides a means for weighing cost against effectiveness.

The analysis process shown in Figure 3 starts when the various alternatives are examined. The consequences that can be expected to follow from each alternative are determined as a function of the model. Costs are weighed against effectiveness and measured according to the criterion. The alternatives can then be arranged in the preferred order to assist the decision maker in making his choice.

In practice, the process may not be as neat as we have indicated: alternatives may not achieve the objectives adequately; measure of effectiveness may not actually measure the extent to which the objectives will be achieved; predictions from the model may be full of uncertainties; and other criteria which appear as attractive as the one chosen may lead to a different order of preference. It is important to recognize that the process is never really complete. The key to successful analysis is iteration. The process is a continuous cycle of formulating the problem, selecting the objectives, designing better alternatives, collecting

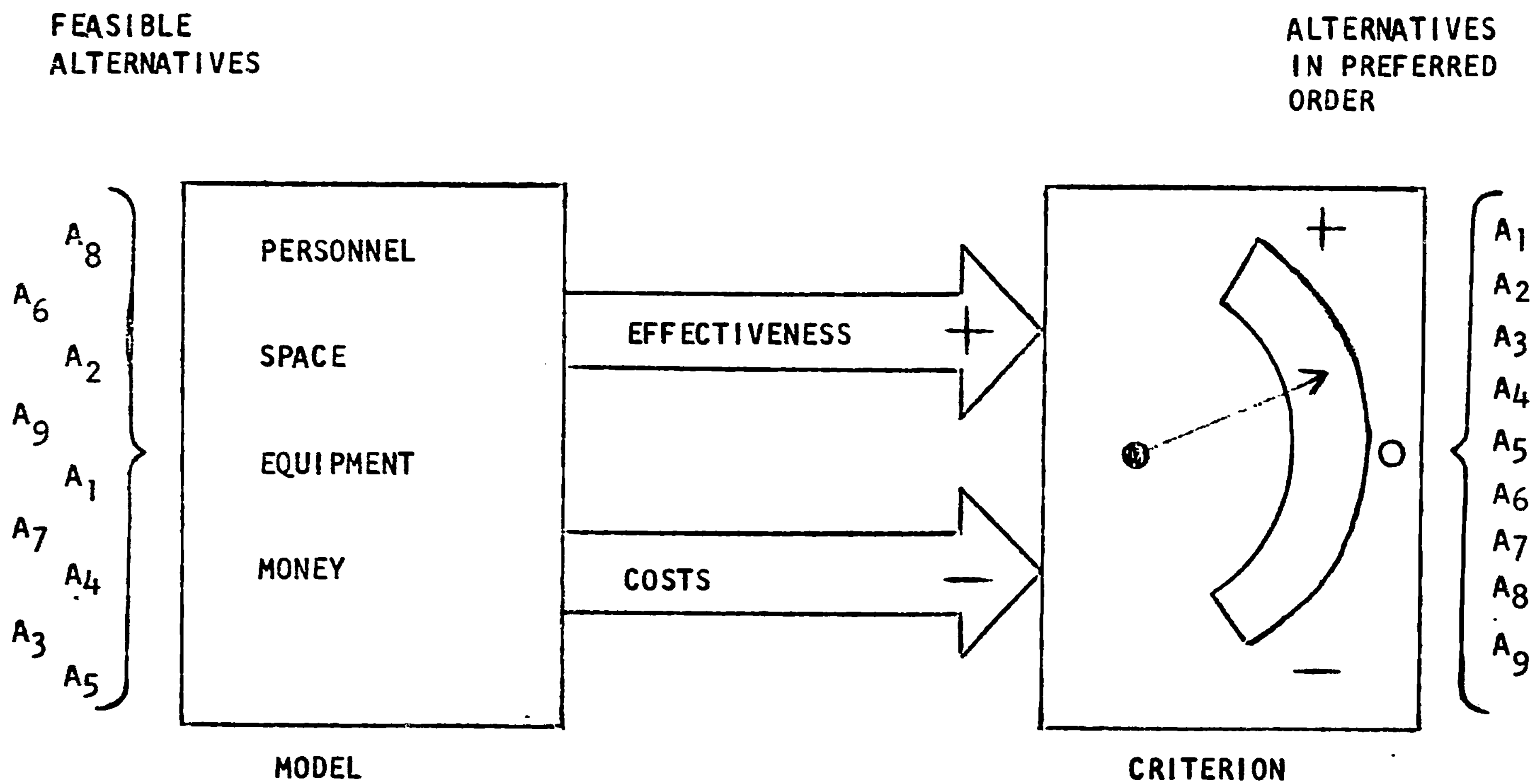

FIGURE 3. THE PROCESS OF ANALYSIS (After Quade)

data, constructing new models, weighing cost against effectiveness, questioning assumptions and data, reassessing the objectives, designing new alternatives, and so on until the desired results are achieved or time and money forces closure.

EXAMPLES OF THE SYSTEMS APPROACH TO DECISION MAKING

The purpose of presenting examples from the literature of the systems approach to decision making is to provide a "feel" for the simulation of educational systems. Since too few examples of computer models exist in education, some examples that are not computerized will be included.

Roger L. Sisson, working with the Philadelphia public school system, has developed a model of a school.[15] Mathematical models are used to relate an index of school performance to selected resource input factors. The average student achievement change over a year in the school is taken as a measure of the performance of the school. The model attempts to show the relationship between resource expenditures and this measure of performance. The model, as developed to date, is static but

---

Roger L. Sisson, "A Model of a School" (Philadelphia Management Science Center, University of Pennsylvania, 1968), (Mimeographed.)

extension to the dynamic case is anticipated. Input factors include staff/student ratio, staff quality, equipment costs, square feet of space, dollars expended, and average grade attained by parents. Output is a measure of the average student achievement over a year in school. The basic phenomena of education is hypothesized to be the interaction of students and adults and the relationship is represented by non-linear mathematical equations. The model contains seven parameters which represent characteristics of behavioral processes (teacher-student; staff-parents; parent-student). The model, if valid, provides a "basis for providing school administrators with quantitative guidance to the decision of allocating funds."[16]

An enrollment projection model being developed by Allan Baisuck, et. al. visualizes the higher educational system as a set of interlocking structural components such as "college curricula", "colleges", or "types of colleges".[17] Each component is, itself, a model with certain inputs, processes, and

---

[16] Ibid., p. 20

[17] Allan Baisuck, Russell C. Koza, and John J. Neuhauser, "A Projection Model for Higher Educational Systems Planning" (paper presented at the May, 1968 Joint National Meeting of the Operations Research Society of America and the Institute of Management Sciences).

outputs. When the components are aggregated, the end result becomes a representation of the higher educational system. Quantification is done in terms of transfer ratios or transition probabilities to allow for compact depiction of student flow by means of transition matrices. The model uses weighted projection techniques throughout. The form of any particular projection is a function of the data involved. Each parametric function projected is designed to provide "the best fit" to the data used, and consequently each projection is to some extent unique. The flexibility, adaptability, and fidelity of the model are a direct function of the level of disaggregation employed in the construction of the model.

Richard W. Judy and Jack B. Levine at the University of Toronto developed a system simulation model.[18] Their effort was given the acronym CAMPUS (Comprehensive Analytical Model for Planning in the University Sphere). The CAMPUS model consists of many pages of computer programs and associated data representing system parameters. The model is limited to the undergraduate instructional activities of a college within the University. The instructional workload of each department is built up and the

---

[18]Richard W. Judy and Jack B. Levine, A New Tool for Educational Administrators. (Toronto: University of Toronto Press, 1965).

resources required are calculated for each simulated year. To do this, the model is divided into four main sections as follows:

1. Enrollment Formulations
2. Resource Loading
3. Space Requirements
4. Budgetary Calculations[19]

Descriptions of the university's structure and statements of the levels of activities expected to be performed are used as inputs. The model simulates the interactions of the university and the resulting output is the resource requirements of staff, space, and money. An outstanding contribution of Judy and Levine's effort is the discussion of the university as a system.

A dynamic, stochastic computer simulation model for subsystems of a university has been developed by Claude T. Cawley.[20] Simulated activities of micro-components such as students, research contracts, and academic personnel are considered in the areas of instruction and research. Parameters for the stochastic operating characteristics are estimated for a department in the University of Utah. The complete simulation model consists of a

---

[19] Ibid., p. 20.

[20] Claude Thompkins Cawley, "Developing a Computer Simulation Model for Systems in Higher Education" (unpublished Doctoral dissertation, University of Utah, 1968).

list of variables defined in terms of computer operations. The functional relationships are expressed as descriptive flow charts. A computer program to implement the model needs to be written and validated before simulated experimentations can begin.

An economic simulation model of an academic unit has been developed by Peter D. Nealing.[21] The model describes fluctuations in the costs of a department within a university when inputs and parameters are varied. Input variables are transformed into a measure of effectiveness such as cost per credit hour by level of study (lower division, upper division, professional, masters, and doctorate). The heart of the model is the policy parameters which reflect historical data and/or the reasoning and attitudes of the decision maker. Quantifiable units are added to subjectively determined parameters to obtain a descriptive model of the department. The model is a collection of linear mathematical equations which represent the functions of a department. A computer program of the model and sample output are available.

The simulation models presented are at different stages of development and differ somewhat in emphasis, but they suggest

---

[21]Peter D. Nealing, "An Economic Model of an Academic Unit" (unpublished Master's thesis, The Ohio State University, 1968).

some of the basic problems and activities associated with the use of the systems approach in the educational environment. "The trend is toward more disciplined ways of evaluating, toward model building, intensive gathering of data, and the weighing of alternatives as a matter of routine."[22]

---

[22]Pfeiffer, *op. cit.*, p. 117.

CHAPTER THREE

THE DESIGN OF COMPUTER SIMULATION MODELS

The term model, especially in educational circles, has been used ambiguously. Some authors use the terms model and theory interchangeably, some use them interchangeably part of the time, and some make a clear distinction between them. A model can be a small representation of a real object (model airplane, for example) and as such is undoubtedly not a theory. Another model can be a characterization of certain natural phenomena. In this case, model and theory may be considered as synonomous.[23] Since we are concerned with the potential use of a computer simulation model as an educational planning tool, the process of developing a model is primarily a problem of deriving a set of characterizations that will represent the system. In this situation, characterizations and not real objects are involved. Consequently, there will be no distinction made between model and theory.

The class of characterization type models is much larger

Elizabeth Steiner Maccia, George S. Maccia, and Robert E. Jewett, Construction of Educational Theory Models: Research Project No. 1632 (Columbus, Ohio: The Ohio State University Research Foundation, 1963), p. 19.

than the class of computer simulation models. For this reason, it is necessary to introduce some terms commonly used to identify types and elements of such models.

TYPES OF COMPUTER SIMULATION MODELS

Computer simulation models are logical and mathematical. They consist of specifications for manipulating symbols of various forms. The symbols may represent a concept, a system, or an operation that can be programmed for solution on a high-speed electronic computer. Martin classifies computer simulation models into three categories: deterministic, stochastic, and expected value.[24]

Deterministic models

A deterministic model is an analytical representation of a concept, system, or operation which is based on assumptions of certainty. Certainty is assumed in the relationships between the components of the system being simulated. There are no variations in the outcome due to chance elements. The computational results are always the same for a given set of parameters and variables. All elements of uncertainty are either nonexistent or removed from

---

[24] Francis F. Martin, Computer Modeling and Simulation (New York: John Wiley & Sons, Inc., 1968)p. 5.

the problem because of irrelevance to the solution.

A deterministic model may be represented by the function

$$X = f\ (A, B, C\ .\ .\ .),$$

where A,B,C. . .are non random parameters and variables. The deterministic method is used wherever chance elements, such as random errors, have negligible effect on the outcomes.

For example, suppose faculty salary A is expected to increase B percent per year and the cost C years from now is desired. The solution is calculated by a deterministic model since there are no chance elements introduced in the problem.

Deterministic models are appropriate whenever (1) chance elements have no effects on the desired results or (2) chance elements are not relevant to the problem.

Stochastic models

The stochastic model, also called randomization or non deterministic, samples probability distributions to determine specific outcomes. The outcome of any particular model run is determined by the Monte Carlo technique. Monte Carlo is a "game of chance" technique to apply random sampling to determine a solution rather than solving the problem analytically or by another method.

In the Monte Carlo solution of complex systems the random features of the system processes are imitated step by step. When the functional relationships in the random features of the model depend upon chance parameters, the values of these parameters are selected from a probability distribution. Therefore, the outcomes in a Monte Carlo model may differ for repeated runs with the same input values. For example, when flipping a coin twice, there are four possible outcomes: head-head, tail-tail, head-tail, tail-head. As a result, to produce statistically significant results in a Monte Carlo model, repeated runs or replications are required with the same inputs that use values from probability distributions in the stochastic functions.

The Monte Carlo approach in computer simulation modeling consists of playing a game of chance in such a way that the random features of the process are exactly imitated step by step. Monte Carlo involves (1) probability distribution, (2) random number generation, and (3) sampling techniques.

For example, suppose faculty salaries which range from A_1 to A_2 are expected to increase B percent each year and the cost for a new faculty C years from now is desired. The solution is determined by a stochastic model. A sample from the probability distribution of the salary range would be determined by Monte

Carlo. Replications would be necessary in order to assign statistical confidence measures to the results.

The stochastic model is appropriate whenever (1) the random features in the system or environment affect the model results, (2) it is necessary or desired to know individual outcomes, rather than aggregated results, or (3) it is desired to derive distribution functions of the results and to compute the variance in addition to the mean.

Expected value models

In the expected (mean or average) value model, the outcomes are characterized by an aggregate of results. Mean values are assigned to the chance parameters and the variance is assumed to be zero. No variance of the results and no distribution of the results is determined. The Monte Carlo procedure would be redundant and, if used, would only produce results similar to expected value and at a greater cost. However, for a hybrid model containing both expected value and stochastic procedures, we could apply Monte Carlo to both.

The expected value model would be appropriate whenever (1) the aggregate outcome is sufficient for problem solution, (2) the model results are not affected by the variations of individuals,

(3) it is not necessary to determine the distribution functions and variance in addition to the mean.

For example, suppose the average faculty salary A is expected to increase B percent per year and the cost C years from now is desired. The solution is determined by an expected value model since the chance elements have been assigned an average or mean value with no variance.

A computer simulation model may contain all or some of the features of deterministic, stochastic, and expected value models. The three models can be contrasted as follows:

1. In deterministic models, the results are always the same for a given set of inputs. No chance elements are introduced and so chance elements have no effects on the desired results.

2. In stochastic models, the results vary depending on the chance elements. This model is applied whenever chance elements affect the desired results and information on the probability distribution of the outcomes is desired.

3. In expected value models, the chance elements are assigned the mean or expected value. This model is applied when the probability distribution of the outcomes is not required.

Most computer simulations utilize hybrids of all three models. The important issue is to apply the right model in the right place. It is necessary to look at the real world; study the problem; examine the expected results; look at resources and time schedule for the the problem solution. These factors should indicate the appropriate model most feasible to apply.

CLASSIFICATION OF MODEL ELEMENTS

Before stating the mathematical model implicitly, or in functional form, the elements must be specified and defined. For convenience, these elements have been classified as <u>components</u>, <u>variables</u>, <u>functional relationships</u>, and <u>parameters</u>.

Components

Components are the elements of the system which are dealt with in the simulation model. The model simulating an educational system may deal with faculty, students, departments, or it may deal with educational systems on local, state or national levels. The components of a particular model depend upon the level of aggregation at which the model operates.

Variables

Variables are attributes or properties of system elements chosen to describe the components of the model. They are those quantities which may assume a succession of values, and they need not be distinct. Variables are classified according to their function in the model. There are three general types of variables and a reasonably set of terms to describe them are: (1) exogenous variables, (2) status variables, and (3) endogenous variables. Exogenous variables are the input variables. They are independent of the system and are associated with the environment in which the system operates. They are determined by factors external to and beyond the control of the system but they have an effect on system performance. Endogenous variables are the output variables. Status variables express the state of components at a specific time. The state of components will change from input to output conditions. Actual classification of a variable depends on the purpose of the simulation. For example, a variable may be considered endogenous if it is required as part of the output even though it may also be an exogenous or status variable at some point in the system's performance.

Functional relationships

Functional relationships are expressions of how the variables interact with one another when the simulated system operates. A formula for computing the secretary-faculty ratio is an example of a functional relationship: it defines one property of a component (e.g. university, college, department). Functional relationships serve to define the formal structure of the model.

Parameters

Parameters provide the substance for a particular system. The values for expressing the functional relationships of a system may be expressed by deterministic, stochastic, or expected value operating characteristic. The actual pattern of one particular situation might be quite different from another. The unique pattern for a particular situation can be specified by probability values or by regression coefficients as the case may be. These numbers are called parameters. For models of real systems, parameters can be determined empirically from data about the system.

CONSTRUCTION TECHNIQUES

Formulation of computer simulation models involve a two-step procedure. First, mathematical models describing the system are formulated. Variables and functional relationships are specified to describe the system. Second, the mathematical models are converted into computer flow charts that lend themselves to the formulation of computer programs.

Building block approach

A "building block" approach is utilized. Beginning with a single block or module of the system and adding additional blocks, a complex system is constructed that can either be analyzed as a whole system or in terms of its separate components. The first blocks are a relatively simple models but each succeeding block adds to the complexity. Each block is dependent on or made up of the previously constructed blocks. The final model consists of a number of blocks or subprograms, each of which was developed in previous models. All of the models are recursive. This means it is possible to sequence one-at-a-time computations of successive values of output variables in such a way that for any time period the value of the output variables can be computated when the input variables and the preceding output variables in the sequence are given. This block-recursive approach to the simulation of economic systems makes it possible to construct flow charts and computer subroutines for larger and more complex operations.

Time increments

Two general types of methods have emerged for moving a model of a system through time on a computer: fixed-time increment methods and variable time increment methods.[25] The fixed time increment method maintains the correct time sequence of events by updating in uniform discrete intervals of time. The system is scanned or examined for every unit of time such as minutes, days, weeks, etc., to determine whether there are any events due to occur at that time. Variable time increment methods update when an imminent event takes place. Events can occur at any desired point in time because time is advanced by variable increments rather than being divided into a sequence of uniform increments.

The final decision concerning whether to use fixed time increment methods or variable time methods depends on the nature of the system. The efficiency of fixed time increment models tend to increase with the number of status variables while the efficiency of variable time increment methods tend to increase with the mean length of events. Experimentation with both methods is appropriate to determine which method minimizes computer running time for a particular problem.

---

[25]Thomas H. Naylor, et. al., Computer Simulation Techniques (New York: John Wiley & Sons, Inc., 1966), p. 126.

CHAPTER FOUR

AN APPLICATION OF COMPUTER SIMULATION MODELS

The objective of this chapter is to develop a computer simulation model which identifies and calculates resource requirements. Input variables must be transformed into units that are both measurable and compatible. The output must be meaningful and useful. First, however, the model can be described in general terms to provide an overall picture for a basis of reference.

GENERAL DESCRIPTION OF THE MODEL

For a general view of the model, attention is focused on simulation of a cluster of programs as the major subsystems of a department. The basic approach is to handle programs one at a time but to provide, where necessary, for interrelationships that may develop between programs as they function in the system. Simulated functions are carried out for a specific period of time. Repeated applications of the model simulate the temporal dimension of system conduct. The time period for this model is taken to be a fiscal year although it would be equally appropriate to use a quarter or a semester.

Computer operations for simulating program functions are identical for each program but each program will have unique parameters. Thus, while input elements are processed the same way for each program, the output for two different programs derived from identical input data may differ because the parameters are not the same. In this manner, individual differences among programs can be realized.

Components of the model (personnel, space and money) are treated separately for convenience in explicating the model. However, the components are interdependent when conducting simulation experiments. Simulation experiments are aimed at expressing the resource requirements in various terms such as numbers of personnel required, square feet of space needed, or money for salaries, travel, maintenance, equipment, etc. Since the units of measure are not compatible, the simulation model is designed to serve three distinct functions:

Personnel function

Personnel are required to meet the demands of the system. For this function, the system is simulated with the personnel component only. Several factors related to personnel are implied. Personnel will be of various types and quantities. The hiring market will supply the system with personnel whenever needed. The characteristic methods of allocating the effort of personnel will determine the outcomes of simulated experiments. If provisions are made to express the increase in number of personnel over time, repeated simulated experiments will perpetuate these characteristics.

Space function

Space is required to meet the demands of the system. For this function, the system is simulated by using personnel and space components. Each type personnel implies the need for a particular type and quantity of space. In addition, there may be special space needs that are dictated by the program. Simulation experiments can be designed to compare space demand generated with space available and to make adjustments as necessary. In such simulation it may be necessary to seek additional space or modify the program. Criteria for making decisions regarding the relationship between space needed and space available can vary considerably.

Money function

Money is required to meet the demands of the system.

For this function, all components are needed. Dollar costs for salaries represent a major money demand. Space needs not satisfied by available space are converted to dollar cost. In addition, cost for equipment, travel, operating supplies, maintenance, etc. are included as a part of the total money demand. Simulation experiments can be designed to compare money demand generated with money available. There may be a need to seek more money or to modify the program.

A particular simulation experiment may consider any or all of the three functions. For convenience the model is presented in three parts as if they were separate. This makes explication of the model simpler but the fact must be kept in mind that the parts are not necessarily independent.

MATHEMATICAL EQUATIONS

The computer simulation model describes the manner in which resource requirements are incurred in a program. The model consists of linear functions which approximate the discrete nature of changes in demand for resources. Consistent data and future analysis will probably dictate some non-linear functions but at this stage of development linearity is the only tentative assumption from which to operate.

Constructing the framework

All university personnel can be classified under a selected group of major categories. For simplification, we will consider only three: faculty, student assistants, and support staff. These categories are divided into subcategories or titles which by definition are mutually exclusive. Only a few titles which are considered to be indicative have been selected for inclusion in this presentation. Titles are represented hereafter with a subscript 'i' as follows:

$i =$ 1 - Professor
2 - Associate Professor
3 - Assistant Professor
4 - Instructor
5 - Graduate Associate
6 - Graduate Assistant
7 - Undergraduate Aid
8 - Administrator - Professional
9 - Secretary - Clerk
10 - Technician and other

The major categories and component titles of personnel are shown in Figure 4.

Categories	Titles
Faculty	1 - Professor 2 - Associate Professor 3 - Assistant Professor 4 - Instructor
Student Assistants	5 - Graduate Associate 6 - Graduate Assistant 7 - Undergraduate Aide
Supporting Staff	8 - Administrator - Professional 9 - Secretary - Clerk 10 - Technician and Others

FIGURE 4. PERSONNEL CATEGORIES AND TITLES

Personnel demand model

The number of personnel in each category assigned to a department or program at any given time can be derived deterministically as output from the personnel demand model. All personnel within the university are identifed as a member of some department. In the program-budgeting context, a department is described as a cluster of programs. Some personnel and some programs may actually be committed to more than one department. In such a case, the percentage of time a staff member is committed to each program or department is determined and an appropriate distribution of the component is made.

Exogenous or input variables for the personnel demand model are represented as:

$STAFF_{nij}$ = Staff member n, type i, in program j.

X_{nij} = Percentage of time for staff member $STAFF_{nij}$ divided by 100.

A full time equivalent (FTE) staff member is represented as:

$$FTE_{nij} = STAFF_{nij}\, X_{nij}$$

where FTE_{nij} = One FTE staff member n, type i, in program j.

The number of staff members (head count) of a specified type in a program is represented as:

$$P_{ij} = \sum_{n=1}^{N} STAFF_{nij} \qquad (4-1)$$

where

P_{ij} = Number of staff members type i, in program j.

N = Total number of staff members.

The number of FTE of a specified type in a program is represented as:

$$PX_{ij} = \sum_{n=1}^{N} FTE_{nij}X_{nij} \qquad (4-2)$$

where

PX_{ij} = Number of FTE type i in program j.

The total number of staff members or FTE of all types in a program or department is represented as:

$$PSTAF_j = \sum_{i=1}^{I} P_{ij} \qquad (4-3)$$

$$PFTE_j = \sum_{i=1}^{I} PX_{ij} \tag{4-4}$$

$$DSTAF = \sum_{i=1}^{I} \sum_{j=1}^{J} P_{ij} \tag{4-5}$$

$$DFTE = \sum_{i=1}^{I} \sum_{j=1}^{J} PX_{ij} \tag{4-6}$$

where

$PSTAF_j$ = Total number of staff members in program j

$PFTE_j$ = Total number of FTE in program j

DSTAF = Total number of staff members in a department

DFTE = Total number of FTE in a department

I = Total number of titles or types of staff members

J = Total number of programs

Information can be generated to establish various relationships among the components. For example, the ratio of faculty to student assistants for a program or a department can be represented as:[26]

$$PFSA_j = \frac{\sum_{i=5}^{7} PX_{ij}}{\sum_{i=1}^{4} PX_{ij}} \qquad (4\text{-}7)$$

$$DFSA = \frac{\sum_{i=5}^{7} \sum_{j=1}^{J} PX_{ij}}{\sum_{i=1}^{4} \sum_{j=1}^{J} PX_{ij}} \qquad (4\text{-}8)$$

where

$PFSA_j$ = Faculty-student assistant ratio for program j.

DFSA = Faculty-student assistant ratio for a department.

The ratio of faculty to support staff for a program or a department can be represented as:

$$PFSS_j = \frac{\sum_{i=8}^{10} PX_{ij}}{\sum_{i=1}^{4} PX_{ij}} \qquad (4\text{-}9)$$

---

26 Subscript "i" can be divided into three selected groups of major categories as shown in Figure 4. Subscript i = 1 to 4 represents faculty, i = 5 to 7 represents student assistants, and i = 8 to 10 represents support staff.

$$DFSS = \frac{\sum_{i=8}^{10} \sum_{j=1}^{I} PX_{ij}}{\sum_{i=1}^{4} \sum_{j=1}^{I} PX_{ij}} \qquad (4\text{-}10)$$

where

PFSS = Faculty-support staff ratio for program j.

DFSS = Faculty-support staff ratio for a department.

A new program may specify the faculty requirements explicitly but assume that requirements for other staff members will be estimated. In this case the model follows expected value procedures. Parameters are employed which use the best estimates or empirical data when they are available. To illustrate, the FTE personnel demand model for a program when only the number and type of faculty are specified can be represented as:

$$PFTE_j = \sum_{i=1}^{4} PX_{ij} + PFSA_j \; PX_{ij} + PFSS_j \; PX_{ij} \qquad (4\text{-}11)$$

or

$$PFTE_j = \sum_{i=1}^{4} (1 + PFSA_j + PFSS_j) \; PX_{ij} \qquad (4\text{-}12)$$

Space demand model

Output from the personnel demand model provides major input for the space demand model. Transformation occurs within the space demand model to get an estimate of square feet of space required. This procedure takes into consideration the patterns of part-time personnel, different types of personnel, program differences, and other factors which force other than a one-to-one relationship between people and the use of space. Only the space needs for staff and special space needs dictated by the program are included in this model. Providing classroom and seminar room space is not included since this function is performed by the office of the Registrar in the Ohio State University's system.

Each staff member requires a certain type and quantity of space. The Office of Campus Planning has established some guidelines. A faculty office should be a private room of at least 120 square feet. Clerical space should be a minimum of 75 square feet per person for multiple occupancy or 100-150 square feet for a single occupant. Student assistants need 75-100 square feet, and professional staff, 90-120 square feet, depending on the nature of their assignment. Special space needs can be any size and type but will be clearly defined in the program. In this procedure, space needs for staff are derived by expected value and special space needs are derived deterministically.

The total space needs for a given program can be represented in the following way:

$$PS_j = \sum_{i=1}^{I} S_{ij}P_{ij}+SS_j \qquad (4\text{-}13)$$

where

PS_j = Total sq. ft. of space for program j.

S_{ij} = Average sq. ft. of office space for staff type i in program j.

SS_j = Special space required for program j.

The total space needs for a department can be represented as:

$$DS = \sum_{i=1}^{I} \sum_{j=1}^{J} S_{ij}P_{ij}+SS_j \qquad (4\text{-}14)$$

where

DS = Total square feet of space for a department

Money demand model

Output from both the personnel demand model and the space demand model are used as input for the money demand model. The financial requirements are derived by relating the costs associated with personnel, space and any special equipment requirements dictated by the program. Salaries for personnel can be determined by using expected value or deterministic procedures. The dollar cost for travel, equipment, and operating supplies for each type personnel is established for each program. For example, each faculty member may be allocated \$150.00 for travel, \$50.00 for maintenance of equipment and \$200.00 for operating supplies, whereas a clerical staff member may be allocated \$100.00 for maintenance and \$300.00 for operating supplies. In addition, any new equipment or any special space needs requiring the construction or remodeling of space may be expressed explicitly as dollar cost.

The program cost can be represented in the following way:

$$PC_j = \sum_{i=1}^{I} (C_{ij}+E_{ij}+O_{ij}+T_{ij})P_{ij} + SEC_j+SSC_j - OR_j \qquad (4\text{-}15)$$

where

PC_j = Total dollar cost for program j

C_{ij} = Average annual salary for personnel type i in program j

E_{ij} = Average annual equipment allocation for personnel type i in program j

O_{ij} = Average annual operating supplies allocation for personnel type i in program j

T_{ij} = Average annual travel allocation for personnel type i in program j

SEC_j = Special equipment cost for program j

SSC_j = Special space cost for program j

OR_j = Outside resources for program j

The total department cost can be represented in the following way:

$$DC = \sum_{i=1}^{I} \sum_{j=1}^{J} (C_{ij}+E_{ij}+O_{ij}+T_{ij})\ P_{ij} + SEC_j + SSC_j - OR_j \qquad (4-16)$$

where

DC = Total dollar cost for a department

Time dimension

Demands for personnel, space, and money fluctuate over periods of time. To make the model dynamic, a temporal dimension is added. Changes in demand can be identified or projected into the future. Equation (4-1) is modified to include a time dimension as follows:

$$P_{ijk} = \sum_{i=1}^{N} STAFF_{nijk} \tag{4-17}$$

where

P_{ijk} = Number of staff members type i in program j and time period k.

Accumulating the number of personnel or square feet of space for periods time would not be useful information. However, accumulating the dollar cost of a program or department can be important. The accumulated dollar cost for a program or department over a period of time can be represented in the following way:

$$APC_j = \sum_{i=1}^{I} \sum_{k=1}^{K} (C_{ijk}+E_{ijk}+O_{ijk}+T_{ijk})\, P_{ijk}+SEC_{jk}+ SSC_{jk} - OR_{jk} \tag{4-18}$$

$$ADC = \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{k=1}^{K} (C_{ijk}+E_{ijk}+O_{ijk}+T_{ijk})\, P_{ijk}+ SEC_{jk}+SSC_{jk} - OR_{jk} \tag{4-19}$$

where

K $=$ Total number of time periods

APC_j $=$ Accumulated cost of program j for K periods

ADC $=$ Accumulated cost of a department for K periods

LOGICAL FLOW CHARTS

A flow chart outlines the logical sequence of events to be carried out in generating the time paths of endogenous variables in the model. Formulating the flow chart is the first step in writing a computer simulation program. Upon completion of a flow chart, the writing of the actual computer code must be considered. The computer program can be written in machine language, a general purpose language such as FORTRAN, or a special purpose simulation language such as SIMSCRIPT. A review of the various simulation languages is beyond the scope of this study. Numerous publications in this area are available.[27]

---

[27] A description of some well known simulation languages and an indication of how they differ from each other is presented by Thomas H. Naylor et al. in Chapter 7 Computer Simulation Techniques (New York: John Wiley & Sons, Inc., 1966), pp. 239-309.

A logical flow chart illustrates the orderly process of activity in the system. The process is illustrated by using various shaped figures connected by arrows to show direction of flow. Within each figure is a statement of what activity takes place. Flow chart symbology has not been standardized. Since no standard conventions are universally accepted, our flow chart activities will be represented by arbitrarily selecting six formats: start/stop, input, computation, decision point, modification, and transfer.

A start/stop point is for reference only and is shown as a circle. An input function accepts data from external sources and is represented by a card-shaped figure. Computational activity is designated by a hexagonal figure. A decision point in which a "yes or no" decision is made is shown as a diamond shaped figure from which the "yes" flow usually continues to the right and the "no" flow proceeds upward. Any modification of any existing value or values by a parameter or index is shown inside a rectangular box. Output is indicated by a print out symbol. These symbols are illustrated in Figure 5.

Personnel flow chart

Figure 6 shows a logical flow chart for our personnel

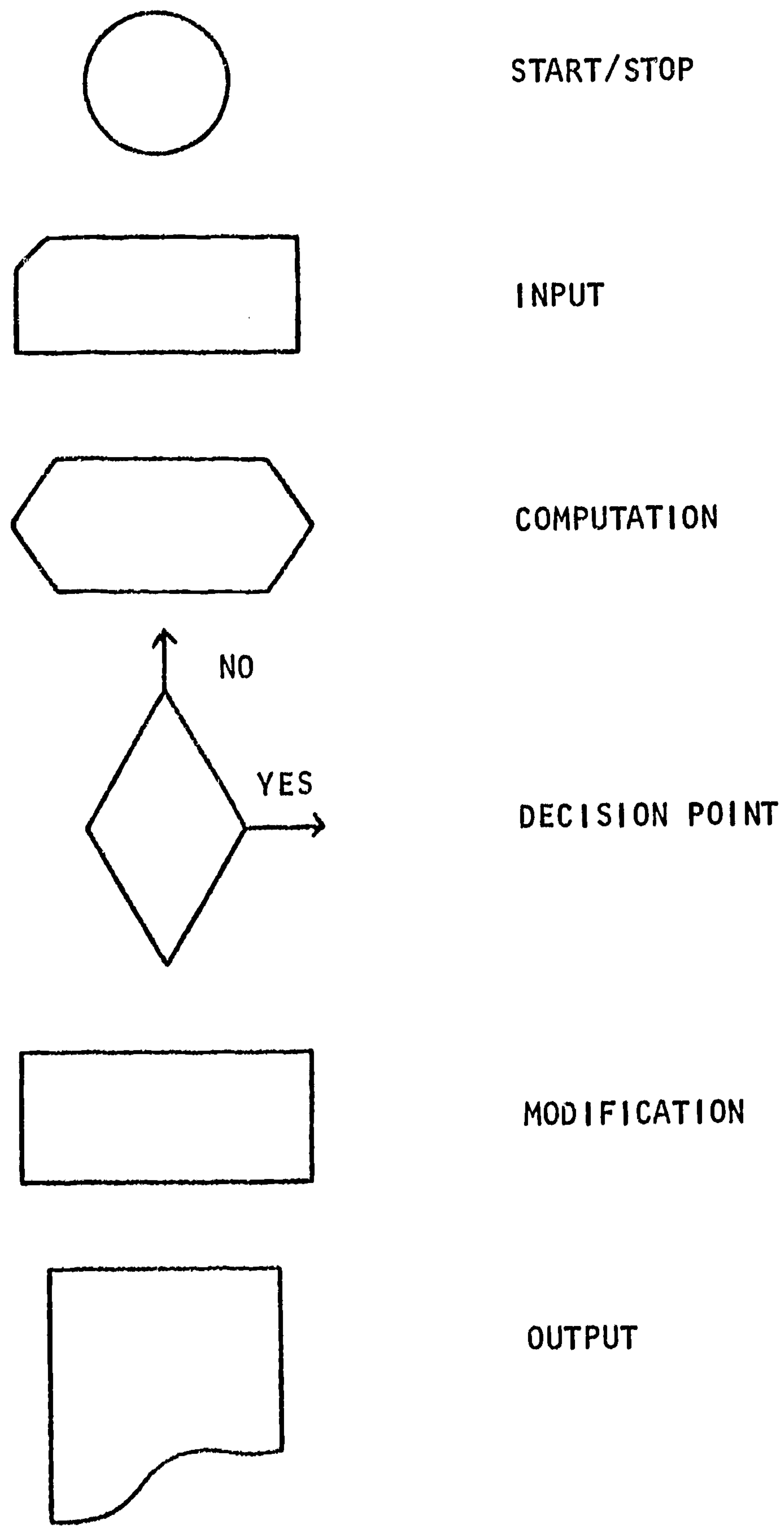

FIGURE 5. FLOW CHART SYMBOLS

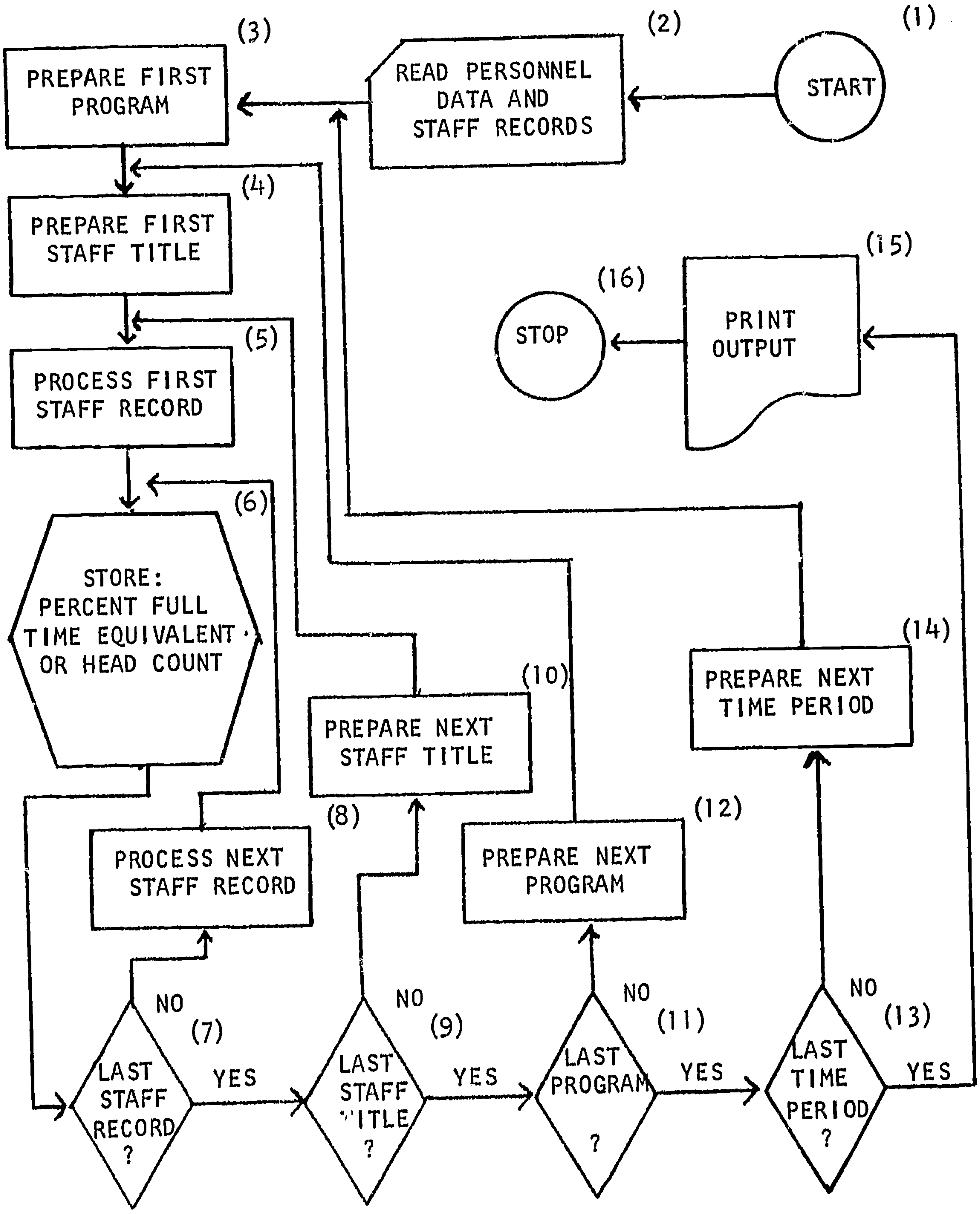

FIGURE 6. LOGICAL FLOW CHART - PERSONNEL DEMAND

demand model. The input consists of initial personnel data and staff records. The initial personnel data includes a list of all titles, number of programs, periods of time to be simulated, and all program parameters. Staff records include title, program, time period and percentage of time for each member of the staff. The process starts when input data are read (box 2). Preparation for the first program occurs in box 3, the first staff title in box 4, and the first staff member in box 5. Percentage of full time equivalency and/or head count are stored in box 6. At the first decision point (box 7), a check is made to see if the last staff member has been processed. If not, the next staff member is processed (box 8). When the last staff member has been processed, a check is made to see if the last title has cleared. If not, the next title is prepared in box 10. The same check is made for the last program in box 11 and the last time period in box 13. When all decision points have been satisfied, the output is recorded in box 15 and the process is complete.

Space flow chart

Figure 7 shows a logical flow chart for our space demand model. Input is the same as for the personnel demand model with the addition of initial space data and special space needs.

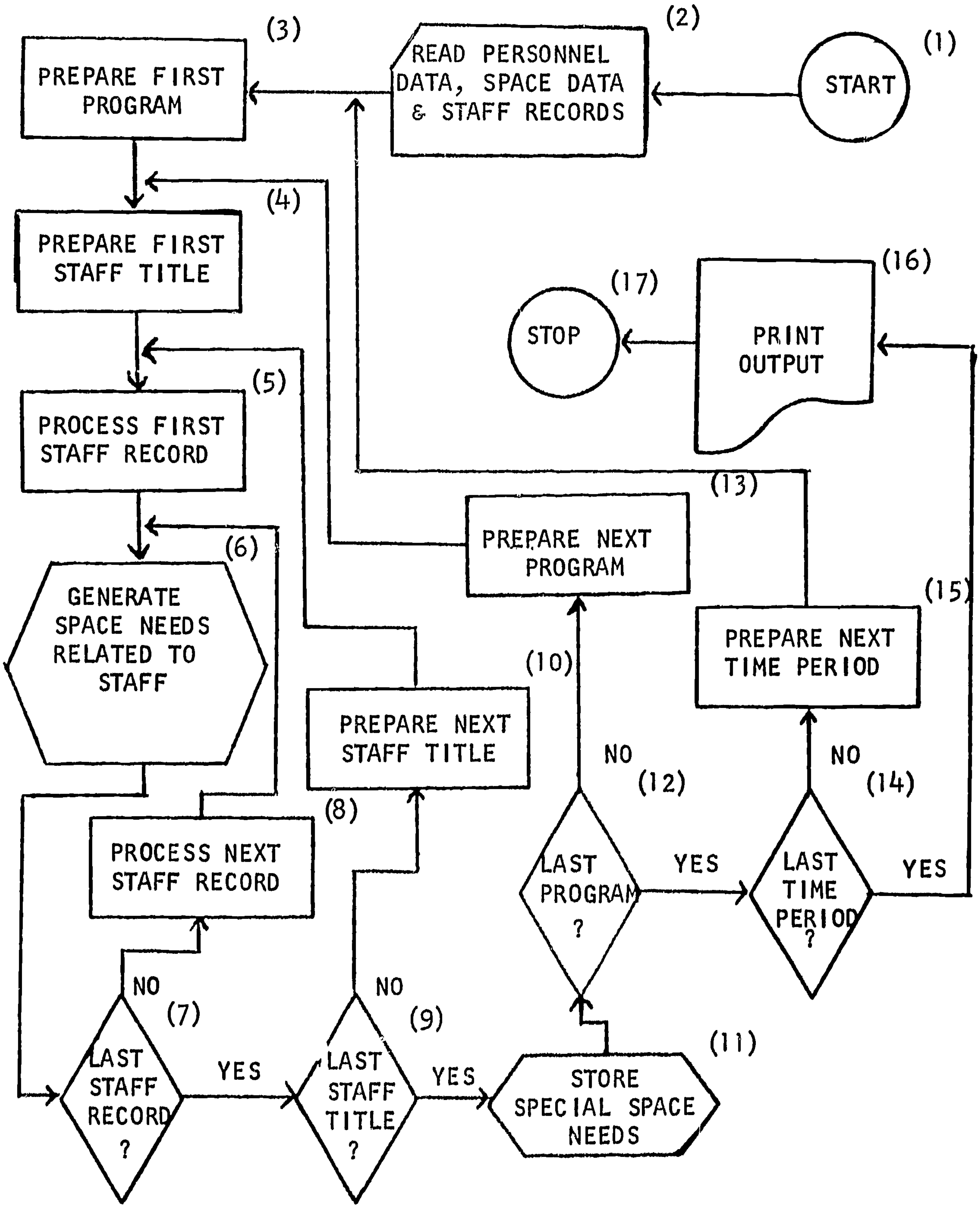

FIGURE 7. LOGICAL FLOW CHART - SPACE DEMAND

The initial space data includes the list of standard space allocations provided for each staff type. Special space needs are detailed explicitly as dictated by the program.

The flow of activity follows the same general patterns as the personnel flow chart. Space demands for each staff member are computed and stored in box 6 and special space needs for each program are stored in box 11.

Money flow chart

Figure 8 shows a logical flow chart for our money demand model. Input includes all inputs for the personnel demand model and the space demand model plus the initial money data and all costs for special space and equipment needs.

The flow of activity follows the same pattern as the previous flow charts. Money demands for salary, equipment, operating expenses and travel are stored in boxes 11 and 12. The process continues until all decision points are satisfied and the output is recorded in box 17.

At certain points in each logical flow chart, specific mathematical equations can be appropriately identified. For example, in Figure 6 the mathematical equation for deriving the number of staff members type i in program j (Equation 4-1) can

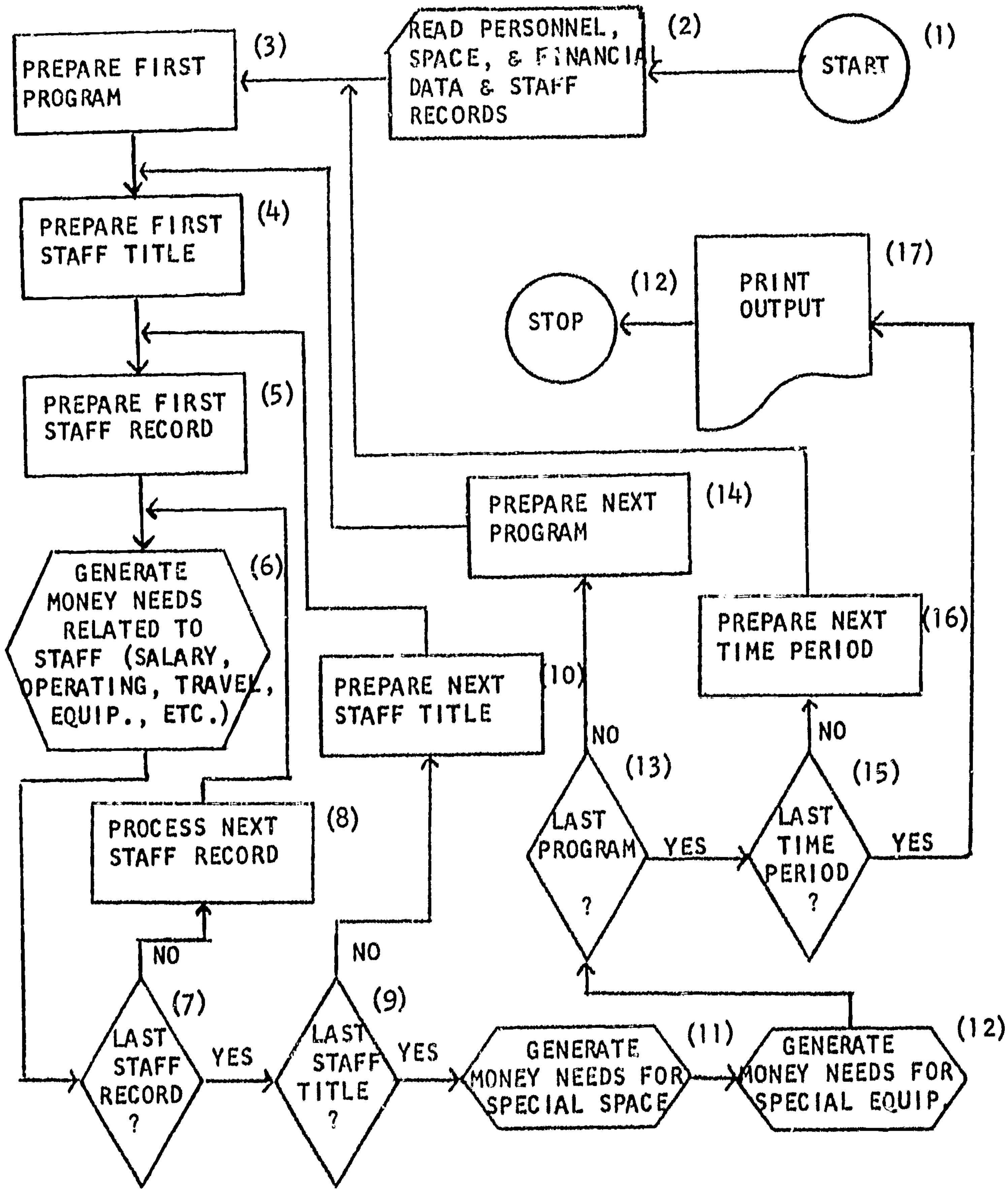

FIGURE 8. LOGICAL FLOW CHART - MONEY DEMAND

can be solved after block 9 is positively satisfied. Similarly, the mathematical equation for deriving the number of all staff members in program j (Equation 4-3) can be solved after block 11 is positively satisfied, and the mathematical equations for deriving the total number of staff members in a department (Equation 4-5) can be solved after block 13 is positively satisfied.

The mathematical equations and the logical flow charts constitute the complete model. Simulation experiments can be carried out with the model by assigning arbitrary values to the parameters. The results, however, would represent an hypothetical system. To apply the model to a real system it is necessary to determine parameters empirically from the system. Estimation of parameters of operating characteristics from real world data is beyond the scope of this project and thus will be reserved for further study. For the same reason, validation of the model must await an evaluation of the parameter estimates.

CHAPTER FIVE

SUMMARY AND EXPECTATIONS

The increasing complexity of educational operations make analytical tools, such as computer simulation models, especially desirable to educational administrators. Continued pressures for efficiency and economy in the educational system call for more and better information to assist in the decision-making process. Computer simulation models can be developed to provide this assistance.

The model developed in this investigation consists of mathematical equations and logical flow charts to depict an economic system in a department of the university. Since the model can be used to establish costs for programs in a department, it should become an integral part of a program budget analysis. Costs associated with present programs can be derived by adjusting the parameters to reflect these programs. Parameters can be varied to represent different operating patterns. Some of these parameters, such as 'DFSS' (faculty-support staff ratio), can be considered to represent the quality of the organization. When the value of this parameter is changed, the cost associated with each level of 'quality' is indicated. For example, a smaller faculty-support staff ratio (and presumedly higher quality) will yield one set of costs, while a larger faculty-support staff ratio (and presumedly lower quality) will yield another set of costs. The model makes no effort to evaluate the quality of the program or to select one program over another. The decision-maker must consider the quality level indicated with its related costs and then make any desired cost-quality trade-off.

At this point, the purposes of the study have been generally accomplished. The systems approach and the decision making process as basic to the development of computer simulation models were described in Chapter II. The design of computer simulation models was covered in Chapter III and a model, consisting of mathematical equations and flow charts, was developed in Chapter IV. The writing of a computer program and validation of the model have yet to be accomplished. Hopefully, these further efforts will be undertaken.

The model does have considerable potential. All possible uses of the model cannot be anticipated. Future modifications cannot be foreseen. However, the following expectations are presently held:

1. The model will provide a micro-level simulation as a nucleus around which other models may be clustered to achieve a more complete simulation of university operations.

2. Existence of the model will make clear the nature of data needed to make it operative. Data for defining parameters are available as outputs of existing university subsystems but they are not collected or summarized in convenient form. A more effective accumulation of data based on the model's structure will eventually provide a secure basis for estimating parameters.

3. The model will be used as an aid in training administrators of higher education. Real or hypothetical parameters can be utilized to operate the model for instructional purposes.

4. Utilization of the model will lead to development of a valid computer program that will allow simulation experiments under a variety of educational policy assumptions. Analysis of probable outcomes of alternative policies will assist decision-makers in long-range planning.

5. The model can provide a unifying effect for departmental planning. Many departments gather information about their own operations but these data are expressed in diverse manners. If departments will cooperate in gathering data to make the model a more precise simulation of their operations, the effort will provide

a focus for unifying departmental planning.

6. The model has potential power for building educational theory. Experimentation with real organizations can result from the extensive work required to determine how various changes in the functional relationships and variables affect the parameters expressing a department's operation. In addition, repeated simulation experiments will reveal trends showing the response of an educational organization to an array of variables.

7. The quality of educational organizations is difficult to define, let alone measure. The model, by simulating the process of an organization, can provide a base for taking a step in this direction.

The model should be available to and used by a large number of people within the university organization. Only as the model is used, and used extensively, can it become a powerful tool. Considerable refinement of this crude approximation will be needed but the more the model is used, the more refined it will become. The significance of this project is that in spite of the incompleteness of the model it is, at this stage, something with which to work.

BIBLIOGRAPHY

Baisuck, Allan, et al. "A Projection Model for Higher Educational Systems Planning." Paper presented at the May, 1968 Joint National Meeting of the Operations Research Society of America and the Institute of Management Sciences.

Cawley, Claude Thompkins. "Developing a Computer Simulation Model for Systems in Higher Education." Unpublished Doctoral Dissertation, Department of Educational Administration, University of Utah, 1968.

Guetzkow, Harold, editor. Simulation in Social Science: Readings. Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1962.

Johnson, Richard A., et al. The Theory and Management of Systems. 2nd ed. New York: McGraw-Hill Book Company, Inc., 1967.

Judy, Richard W. and Levine, Jack B. A New Tool for Educational Administrators. A Report to the Commission on the Financing of Higher Education. Toronto: University of Toronto Press, 1965.

Maccia, Elizabeth Steiner, et al. Construction of Educational Theory Models; Research Project No. 1632. Columbus, Ohio: The Ohio State University Research Foundation, 1963.

Martin, Francis F. Computer Modeling and Simulation. New York: John Wiley & Sons, Inc., 1968.

McMillan, Claude, and Gonzalez, Richard F. Systems Analysis: A Computer Approach to Decision Models. Revised Edition. Homewood, Illinois: Richard D. Irwin, Inc., 1968.

National Science Foundation. Systems for Measuring and Reporting the Resources and Activities of Colleges and Universities. NSF 67-15. Washington, D.C.: National Science Foundation, 1967.

Naylor, Thomas H., et al. Computer Simulation Techniques. New York: John Wiley & Sons, Inc., 1966.

Nealing, Peter David. "An Economic Model of an Academic Unit." Unpublished Master's thesis, The Ohio State University, 1968.

Orcutt, Guy H. "Simulation of Economic Systems," American Economic Review, L No. 5 (December, 1960), pp. 897-907.

Pfeiffer, John. New Look at Education: Systems Analysis in Our Schools and Colleges. New York: The Odyssey Press, 1968.

Quade, E. S. and Boucher, W. I. Systems Analysis and Policy Planning: Applications in Defense. New York: American Elsevier Publishing Company, Inc., 1968.

Sisson, Roger L. "A Model of a School" Educational Intermediate Unit Study, Management Science Center, University of Pennsylvania, Philadelphia, Pennsylvania, 1968. (Mimeographed.)

Timms, Howard L. Introduction to Operations Management. Homewood, Illinois: Richard D. Irwin, Inc., 1967.