A SYSTEMS MODEL FOR UNIVERSITY RESOURCE ALLOCATION

By

VAUGHN KENNETH GRACE

Bachelor of Science
United States Naval Academy
Annapolis, Maryland
1961

Master of Science
Oklahoma State University
Stillwater, Oklahoma
1963

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
DOCTOR OF PHILOSOPHY
August, 1969

A SYSTEMS MODEL FOR UNIVERSITY RESOURCE
ALLOCATION

Thesis Approved:

Charles M. Bacon
Thesis Adviser

Kenneth A. McCollom

James E. Shamblin

Rao Yarlagadda

R. E. Chapel

D. D. Durham
Dean of the Graduate College

ACKNOWLEDGEMENTS

I wish to express my sincere thanks to my thesis adviser, Professor C. M. Bacon for his guidance, encouragement, and aid throughout my doctoral studies. I am grateful for the many hours he devoted on my behalf and for the inspiration and enthusiasm that he engendered.

I also wish to thank my committee chairman, Professor K. A. McCollom, for bringing to my attention the work of Dr. Koenig at Michigan State University and for his guidance during my doctoral study program. I am also indebted to the other members of my graduate committee, Professors J. E. Shamblin, R. Yarlagadda, and R. E. Chapel for their encouragement and time spent on my behalf.

To Dr. Koenig at Michigan State University, I wish to give thanks for his correspondence and encouragement.

I wish also to express my thanks to W. M. Usher, Computer Center Director, G. K. Jones, Assistant Registrar, and W. V. Accola, Programming Supervisor of the University Computer Center, for their help on my behalf.

I wish to acknowledge both my sponsor, the United States Air Force, and my typist, Mrs. Dixie Jennings.

Finally, to my wife, Norlian, I express my warmest appreciation for her encouragement and sacrifice during my graduate studies.

TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure Page

CHAPTER I

INTRODUCTION

Statement of the Problem

There are many topics of discussion today on which there is dissent, but one topic on which most people will agree is the need for more opportunities for high quality education. Our technological society needs an increasing number of educated and trained people to meet the demands of a growing population. The entire educational system of the United States is faced today with problems arising, in part, from a growing student population and increasing costs of education.

The decade that lies ahead offers even greater challenges to our educational system. The U.S. Office of Education estimates that there will be 9.4 million students enrolled in our colleges and universities by the school year ending June, 1977, compared with 6.9 million in the Fall of 1967 and that college and university spending will climb from $16.6 billion in 1966-1967 to $27.8 billion in 1976-1977 (1). These figures are based on the assumption that enrollment will continue to increase and that the expenditures per student will continue to rise at all levels at the same rate as in the past ten years.

Oklahoma, like most other states, is already faced with a financial crisis in higher education. As a result of this financial crisis, a resolution limiting Oklahoma college and university enrollments to 75,000 students for the 1969-1970 school year was introduced in the State

Legislature in January, 1969 (2). Although not adopted, the effect of this resolution would have been to deny for at least a year access to State college classrooms for some estimated 5,000 students. State college presidents told a joint hearing of the State Senate and House approiations that few alternatives to greater financial support from the State are available - these being higher tuition, higher student-teacher ratios and/or limitation of enrollments.

It appears that the proposed resolution to restrict enrollments was selected to dramatize the financial problem that now exists in State support of Oklahoma colleges and universities. The present financial crisis facing higher education is not limited to Oklahoma but is clearly a problem of national concern. Restricting enrollments is not an acceptable solution for Oklahomans and it can hardly be an acceptable solution for the nation as a whole.

Faced with strict funding levels, Oklahoma colleges and universities must take appropriate steps to improve the utilization of their resources. This does not mean that better utilization of educational resources alone will solve the financial problem nor is it intended to mean that presently available resources are not used efficiently. There is the implication, however, that traditional educational methods may be changed with advantage to both students and faculty with a savings of resources (funds, equipment, space, personnel effort, etc.).

What are some of the ways in which resources can be better utilized? An obvious way is to make greater use of present space, e.g., classrooms, by scheduling classrooms more hours each week and filling them to capacity. The Fund for the Advancement of Education (3) in a study of methods to maintain a high quality education for an increasing number of students suggests other ways in which traditional educational methods may be changed with advantage to both students and faculty. The conclusions voiced in the study are the following:

1. Many more students are capable of doing a large amount of work independently of classroom instruction than have been given the opportunity to develop their capacities for independent work, and the quality of their work will be as good or better than under present methods of instruction.
2. Students need to be carefully prepared for independent study to benefit most from it, but with such preparation average and slow students can do well.
3. The quality of the teacher has far more effect on student learning than the methods of teaching used or the size of the class taught. Consequently the best teachers should be made available to more students, and one of the best ways of doing this is to provide for large classes taught directly or over television.
4. Students learn as much in large classes as in small ones, and the loss of personal contact sometimes noted can be overcome by judicious use of class groups of widely varying size, both larger and smaller than customary, and by greater use of capable assistants.
5. Inertia of faculty and administration is largely responsible for the slow pace of desirable educational change. When faculty members earnestly seek means of improving instruction for more students, many new methods less wasteful of faculty time can be effectively used. Much more and more far reaching experimentation is needed.
6. Colleges have made far too little use of modern technology to overcome faculty shortages.
7. There are teaching resources in many communities which could be tapped for part-time teachers if colleges would change their attitudes toward such staff members and properly induct them into their professional duties.

One fact is clear. Many new approaches to instruction and the teacher-student interface are being suggested and tested to determine their educational effectiveness. However, decisions by university administrators on whether to totally implement any new approach or innovation must take into account the cost of the university resources required. Evaluating alternative teaching methodologies requires that cost-effectiveness relationships be developed. The development of realistic cost-effectiveness techniques for administrative decision-making implies a parallel research effort. First, researchers with a background in educational processes must develop refined testing and evaluation methods for evaluating, in a quantitative fashion, the effectiveness of alternative man-machine systems of instruction. Secondly, an equal amount of research emphasis should be placed on the development of mathematical models to simulate the utilization of personnel and physical plant resources which would be required to implement a new instructional system. This latter research area is the subject of this dissertation.

The subject of resource allocation in higher education has been investigated from both the experimental and theoretical points of view for many years. Recent attempts to model resource allocation in higher education using modern system theory concepts indicate that substantially more extensive investigations need to be done on this subject. Typical questions to be answered are: What variables and parameters are important in assisting administrators to allocate resources to meet constantly changing demands and needs? What units should be used to measure variables and parameters? What services are provided by institutions of higher education and what are their costs? Who generates the demands for services and to what degree? What are the various interrelationships among the components and functions of an institution? Can these relationships be described mathematically? Can a model be formulated to describe how resources are allocated? What types of resources are utilized? Can control variables that influence the student population distribution be identified? How much does it cost to provide credit hours of instruction in various disciplines? What is the cost of producing a graduate at the B.S., M.S., or Ph.D. level in a specific discipline? How can these costs be determined from readily available data? The prototype model described in this dissertation was developed with questions such as these in mind.

This dissertation then is concerned with formulating a detailed prototype resource allocation model of the College of Engineering of Oklahoma State University. The College is an important part of the University and aptly demonstrates the "building block" approach. The "building block" approach means that the model of the College of Engineering can be considered to be a basic component model of the University system. Models of the other colleges of the University might be formulated by using the College of Engineering model as a prototype with appropriate modifications for differences in detail. The model of the University could then be obtained by combining the models of the individual colleges of the University. The point is that this prototype model provides a foundation for the development of more general resource allocation models.

A primary aim of this study involves quantitatively describing the patterns by which College administrators allocate resources in order to meet the demands for services imposed upon the College. It should be noted that it is not the intent of this study to analyze the allocation of funds to the University by the State Legislature through the State Board of Regents. Also, no attempt is made to analyze the patterns of resource allocation by University administrators to the various colleges of the University. Rather, the problem of concern is how the schools of the College allocate their resources.

Approach to the Problem

The general approach to the problem was to develop a detailed model using certain characteristics of input-output analysis developed by the economists combined with modern system theory developed by the scientists and engineers. In this model, the College is viewed as a collection of interacting parts, components or sectors. This approach has previously been used successfully by economists in the analysis of complex socio-economic systems. The model is characterized as dynamic since it contains a system of first-order coupled difference equations in normal form. This is commonly referred to as a state-space model. Dynamic models of the state-space form have evolved as the basis for analysis, simulation, control, and optimization in modern system theory. The extensive literature on simulation, control, and optimization applies directly to socio-economic systems when they are modeled in this form.

One of the best ways to study resource allocation in the College of Engineering is to describe the administrative organization and the functions (services) performed by the College. In order to obtain the state-space form, the College system is viewed as being comprised of two interacting sectors; namely, a student sector and a production sector. Each sector is conceptually removed from the College system and studied in isolation. The system model of the College is then obtained by combining the two sector models.

The model described in this dissertation has the following identifying characteristics: It is a dynamic, linear, discrete-time, deterministic model. All variables may vary with time, are assumed to be linearly related, and are assumed to be known or can be measured only at discrete times.

It is realized that there may be non-linear relationships in the input-output characteristics of the College and that the present model is only a first-order approximation. However, what is not obvious is what relationships might be non-linear. Also, linear relationships are often good approximations for short intervals of time. As non-linear relationships are identified, they can be incorporated into the model.

The model is formulated as a deterministic rather than a stochastic model. Once sufficient data is available to determine the statistics of past operation, then it is possible to arrive at a probabilistic model that can be used for prediction.

Uses of the Model

The model is designed to provide information concerning past and present operation of the College. The University has already created a student as well as faculty and staff data file. The student file contains information taken from class cards and student registration records. The faculty and staff file contains information taken from the Request for Personnel Action form and application forms. Data is primarily stored on discs for random access capabilities. Inactive files are pulled off disc storage and stored on magnetic tape. Additional steps are being taken to make these files more complete. Once a suitable data base has been developed, then such useful statistics as cost figures, trends, etc. can be provided by the model in an automated fashion.

The model of the student sector contains a student population model which describes movement of students through the College system. The student population model provides information, primarily by school and student level, concerning the number of students continuing in the College from one semester to the next; the number of students, classified according to type, that enter the College from off-campus; the number of students, by college, that transfer into the College from other colleges on campus; the number of College students awarded graduate or student assistantships; and the number of students that leave the College.

The model not only calculates the number of students enrolled in each school of the College, by student level, a statistic already available from other sources, but also provides information concerning the proportion of students that were enrolled in the College during the past semester and that are still enrolled in the College during the present semester. It also calculates proportions representing the school and student level choices of arrivals from both on and off campus. This information is new. Once data has been collected for past semesters and trends are established, the model can also be used in predicting the future population make-up of the College.

In addition, the student sector model can be used to determine exactly how many students leave the College during a given semester and their classifications prior to leaving. This statistic is difficult to determine from present records. A computer program has been written to determine the transitions and transfers described above. A discussion of this program is provided in the Appendix.

The student sector also describes student demands for credit hours of instruction imposed upon the College. Implementation of this feature will provide new information concerning average credit hour loads of students enrolled in the College.

Finally, the student sector develops equations that impute an average cost (value) to students enrolled in the College (by school and student level) based upon the cost of credit hours of instruction taken by these students. This development, which provides new information, is intended as a first step in determining, ultimately, the average cost involved in producing a Bachelor's, Master's, or Doctor's degree in each school of the College. Credit hour costs are determined from the costs of resources utilized in producing them.

The costs of instruction are determined in the production sector model which describes the input resources utilized by the College and the corresponding products produced in terms of input-output models. Equations that can be used to calculate unit costs are also developed in the production sector. Implementation of this sector will allow unit costs (dollars per student-credit-hour) as well as individual course costs, student-credit-hour costs by school and course level, etc. to be calculated.

The University makes an annual study of instructional salary costs per student-credit-hour produced according to lower-division undergraduate, upper-division undergraduate, and graduate courses (4). Information for this study is obtained from a questionnaire sent to each department. The costs per student-credit-hour are based on personnel costs only and do not include physical plant costs, computer costs, etc. Once a suitable data base is developed, implementation of that portion of the production sector that computes student-credit-hour costs could eliminate the need for gathering information by questionnaires. Cost figures could be provided automatically with an option of more detailed calculations and with certain non-personnel expenditures included in these calculations.

A computer program has been written to determine course costs, student-credit-hour costs for individual courses, the full-time-equivalent effort of personnel per student-credit-hour produced for individual courses, and object expenditures per student-credit-hour produced for individual courses. A discussion of this program is provided in the Appendix.

The production sector model formulates input-output models for instruction, research, and extension. Unit cost equations are formulated also. Total implementation of this sector will provide cost figures for individual institutional and sponsored research projects as well as cost figures for extension activities.

The system model results from combining the two sector models. The system model does not provide any new statistics with respect to those already described for the two sector models. However, the system model does describe explicitly the interdependence of the two sectors and it describes the operation of the College as one integral unit.

The system model can serve as a simulation tool in ascertaining the effects of changing allocation policies. For example, administrators can use the model to simulate the effects of changing the mix of resources utilized in instruction, research, and extension programs and observe the resulting costs.

The uses of the model given in this section certainly does not exhaust all possibilities. However, some of the more important uses of the model have been described.

In brief summary, the objective of this dissertation is to formulate a detailed prototype resource allocation model of the College of Engineering. The approach to the problem was to develop a model of state-space form. A state-space model is desirable since the extensive literature on simulation, control, and optimization applies directly to systems modeled in this form. There are many possible uses of the model described in this dissertation. One of the more important uses of the model involves simulating the effects of changing the mix of resources utilized in instruction, research, and extension.

CHAPTER II

REVIEW OF LITERATURE

Other Modeling Efforts

In recent years considerable effort has been devoted to mathematical modeling in education. The models range from simulations of various phases of operation of particular institutions to models that purport to describe the entire educational system.

A good critique of the methods and models for human resource development planning up to the year 1966 is presented by Davis (5). By the term "human resource development" Davis means education and training of members of society. He critiques three different types of general educational models used for setting output targets and allocating resources to education. The different model types are the following: 1) the first model type assumes a set of political, cultural, or social goals requiring that some specified portion of the population has a right to some specified amount of education and training; 2) the second model type utilizes estimates of the resources (human and fiscal) available for assignment to education and training so that returns are maximized; and 3) the third model type assumes a set of human resource requirements or targets in the work force. The objective is to equal or exceed the targets with allocations minimized.

Some of the models for human resource development critiqued by Davis use linear programming techniques. The sole advantage of this type formulation is that it does give a simple and idealized version of how education and the economy might work and might be planned. However, the dilemma in using linear programming techniques is that the educational system is fit to the linear programming format which results in the model being either too general to be useful or too complicated to be manageable.

A research demographic model of the formal American educational system is reported by Zabrowski et al. (6). A computer model called DYNAMOD II is developed by the authors. DYNAMOD II is a computerized Markov-type model which calculates the responses to changes in its parameters for 140 population groups over selected intervals of time. These population groups are composed of four sex-race groups cross-classified as to age (six categories) and educational status (three levels each of students and teachers as well as elementary and secondary school dropouts). Included also are "other" categories which contain the segments of the population which are classified as not being in the educational sectors.

The model uses over 832 transition probabilities to estimate the population flows in each year. Birth projections are introduced independently into the appropriate sex-race categories after each iteration of the model.

Stone (7) outlines a general model of the educational system designed to work out the present implications of future levels of educational activity as determined by the evolution of the demand by students for training and the requirements for trained personnel by the economy. By educational system, Stone means schools, universities and all forms of professional and industrial training. He studies the educational system with the aid of an educational matrix similar to the industrial input-output matrix in Leotief's model.

The different stages of the educational system are regarded as industries, or processes, through which the students pass, first as raw materials, then as semi-finished products, and eventually as final products, or graduates. For any individual, graduation takes place when he passes out of the system, regardless of the stage he may have reached at the time.

Merck (8) has developed a Markovian model that provides projections of a population to some point in the future based upon existing policy conditions. His model describes movement of Air Force personnel through categories ("states") which are defined by career fields and enlistment terms. A computer-processed model was developed for use in personnel planning. One of the major uses of the model is to evaluate the effects of a policy change. Merck uses the concept of "states" in his model. This concept is also used in the student population model described in this dissertation.

An example of a computer simulation model that simulates a particular operational phase of an educational institution is GASP (Generalized Academic Simulation Programs) (9). GASP can be used for scheduling classes by assigning time, instructors, rooms, and students to the classes being offered. Thus GASP is, to a degree, a resource allocation model. Earlier versions of the GASP program were written in 1961-1962. The latest version of GASP (GASP III) was implemented on 360 computers in 1967. All versions of the program were developed and written at the Massachusetts Institute of Technology.

O'Brien (10) presents a cost model for large urban schools. He describes the mathematical equations required to estimate the cost resulting from the construction and operation of a large school facility. The equations are presented in parametric form, with only limited data presented for the estimation of parameters. The costing procedure is developed to the extent that new facilities and staffing costs are estimated independently of the existing system. Some of the cost elements which are discussed and for which mathematical formulas are given, are the following: construction of new school plants, personnel staffing, acquisition of special equipment, and acquisition of land. His model could be used in combination with the model described in this dissertation to estimate the costs described above.

Planning for future college needs is one task that is simulated by a computer at Hiram College in Hiram, Ohio (11). Using a mathematical model of the operation of the College, Hiram administrators can introduce a theoretical change in one area of the College and by simulation, observe the resulting effects on other areas of the College. The College also uses the same computer for grading, class scheduling, and accounting. Unfortunately, the matematical model of the College is still being refined and no further information concerning its characteristics will be released until sometime in the future.

"Input-output analysis" or interindustry economics is concerned with quantitative analysis of the interdependence of producing and consuming units in a modern economy. In particular, input-output analysis studies the interrelations among producers as buyers of each others' outputs, as users of scarce resources, and as sellers to final consumers. The first empirical input-output model was formulated by Leontief. In a manner similar to Leontief, Raphael (12) has formulated an input-output model of Pennsylvania State University. His model can be used for controlling the operations of the University, studying the effects of changes on the operations, and for management decision-making by simulating alternative courses of action. The University is divided into 47 sectors. His model is deterministic and simulates the flow of funds and other appropriate units through the various parts or sectors of organization. Although Raphael's model treats the University as a collection of 47 separate sectors, it should be noted that the sectoral breakdown is not fine enough for analysis of an individual department. Also, the model is static rather than dynamic.

Thus far, general models of the educational system have been presented. These models are formulated in gross terms and are not capable of providing the detailed information desired in this study. The desired objective is to structure a detailed mathematical model that will aid College administrators in the allocation of resources. The type model desired is one structured as a set of interacting sectors. In particular, a state-space formulation is desired. A model with a state-space formulation specifically designed to answer some of the questions proposed in Chapter I is described next.

Michigan State University Model

Koenig, Keeney and Zemach (13,14) have been developing and refining a mathematical model of an educational institution since 1964. Their model is general enough and flexible enough to be adapted to any institution of higher education, or to a single institution as it changes in time. This is possible within the conceptual structure described by the authors by allowing variables to be redefined or modified to adapt to institutional differences.

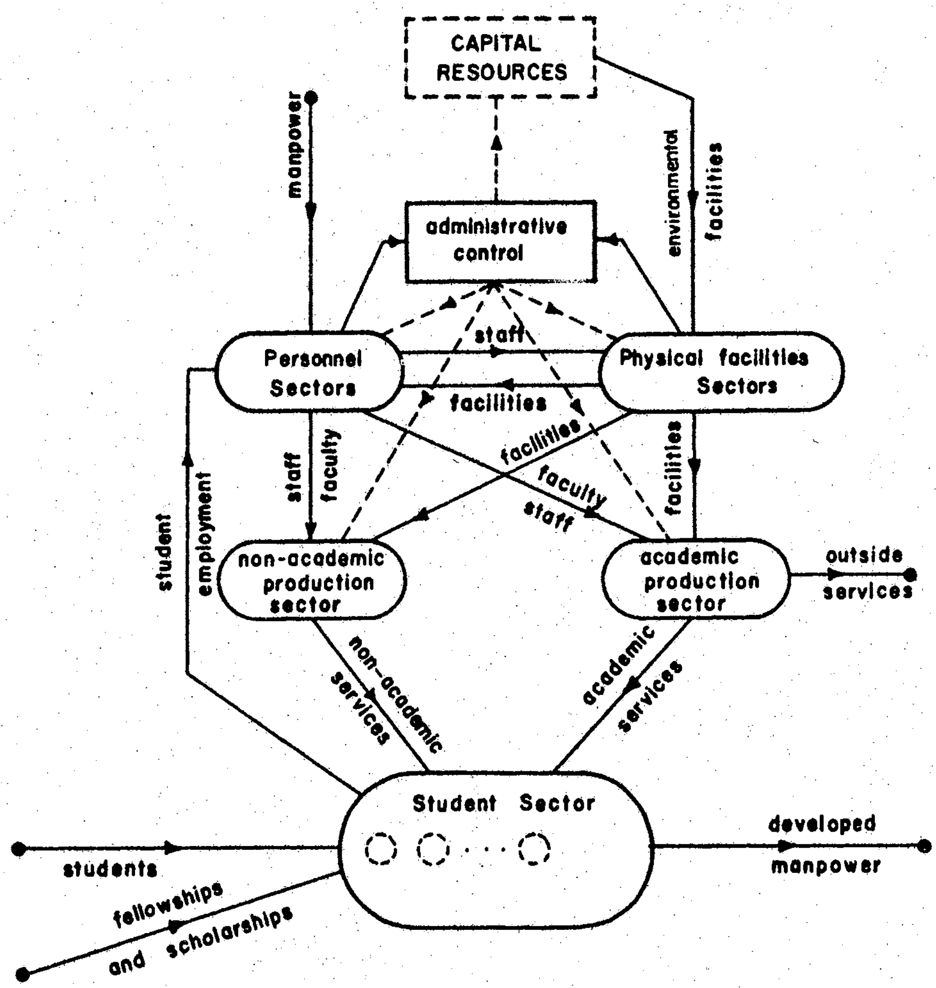
The research effort described by Koenig *et al*. is by no means completed. Almost every stage of development is represented in some part of their model. Certain components are in the first stage of theoretical modeling, while for others, data processing and simulation programs are completed. A brief description of the MSU model is now presented. Those interested in a detailed technical description of the model are referred to Reference 14.

The model consists of sets of equations which describe the relationship of resources to production, and, based on these, the associated unit costs of production. It is therefore a mathematical description of the way in which the University utilizes its resources in production. The resources of the University are described, broadly, as personnel, space, and equipment. The products are identified as developed manpower, research, and public or technical services.

The schematic diagram in Figure 1, taken from Reference 14, identifies the major sectors or components of University activity established by the model and the variables used to determine the behavioral characteristics of each sector. Note that the sectors are functional and do not represent the administrative divisions of the University.

The MSU model identifies a student sector, production sectors related to academic and non-academic services, and resource sectors for personnel and physical facilities. Also, an "administrative control" sector is indicated as a source of policy decisions.

The model of the student sector describes the internal state of the University at any particular time in terms of the distribution of students among the various areas of education and levels of study and the respective average accumulated costs per student of education to that



—— vector flows of people and services with associated imputed values per unit

---- administrative policy controls

● interfaces with remaining socio-economic process (terminals)

◌ population groups and their imputed values (internal states)

Figure 1. Basic Structure of a Typical Institution of Education as a Socio-Economic Process

point in time. The model of the student sector also describes the number and educational status of the students who leave the University and the number of student credits and hours of research-teaching that must be produced to satisfy the demands of the student body.

The equations of the academic production sector describe the relationship between the quantities of academic services produced and the quantities of faculty effort, graduate assistant effort, and environmental facilities such as classrooms, laboratories, and technological equipment, required to produce these academic services. The description of this sector also includes the cost of services produced, based on the costs of resources required.

The equations of the sector described as non-academic production indicate the quantities of effort and facilities required to meet student demands for services such as housing, registration, counseling, and medical service. No attempt has yet been made to model non-academic production in detail.

The resources required by the academic and non-academic production sectors are considered to be produced by the resource sectors of university operation referred to in the model as Personnel and Physical Facilities Sectors. Extensive use of these sector models awaits further developments in computer-based accounting systems.

Units of effort and facilities are also required by the sector identified as Administrative Control. The function of this sector is to issue administrative policy control over the resources utilized by other sectors involved in production.

The structure of the system model allows an independent model of capital resource development to be incorporated into the structure if the allocation patterns can be determined.

The system model of the University is then obtained by combining the sector models.

The research effort described by Koenig et al. does not end with the model of the educational institution. Rather, the authors then consider the mathematics of control and how their model might serve as a model for a set of institutions of higher education operating in parallel and, with further generalization, as a model for the total educational system.

Contributions of This Effort

The first contribution of the model described in this dissertation is that it is a pioneering effort, i.e. no resource allocation model of the College of Engineering existed before this effort. The modeling approach, i.e. the use of a component or sector structure, was inspired by the work of Koenig at Michigan State University. However, the final model has many new features not contained in models proposed by Koenig and other investigators.

The first difference lies in the detail shown in this model. The production sector described in Chapter V identifies resource allocations to individual courses and specific programs in research and extension. This detailed breakdown is not given in the models of Pennsylvania State University or Michigan State University. Thus, one contribution lies in identifying the specific components of the various vectors and the units used to measure them.

A major difference in approach between this model and the MSU model concerns the way in which costs per time period for expenditures other than personnel are handled. The MSU model multiplies the units utilized per time period times the dollar expenditure per unit to obtain the dollar expenditure per time period. This approach has several disadvantages. First, it requires each item to be of a homogenous nature, e.g., paper clips and paper cannot be lumped together in the model as "supplies and material". The second disadvantage is the accounting burden that is required to itemize both the number of items used and their unit costs. In the model presented in this dissertation, expenditures for items other than personnel are simply given in terms of dollar expenditures per time period. These are the type records that are presently kept and most easily recorded.

There are other differences between this model and the MSU model. These differences also delineate contributions. For example, the sectors defined in this model are organizational as well as functional, whereas in the MSU model, the sectors are functional and do not represent the administrative divisions of the University. Another difference between this model and the MSU model is that this model also describes the use of student assistants in production.

A considerable amount of effort in this study was devoted to investigating thoroughly the data base presently available. Conferences were held with many College and University administrators and officials in order to determine the present data base as well as to discover future plans in this area. The model was then formulated after the available data were known. Thus, an important contribution of this effort is the closeness and relevance of the available data base to the model structure. The data required to implement the model are feasible and available although they may not yet be in a computer processable form.

CHAPTER III

STRUCTURE OF THE MODEL

This chapter briefly describes the administrative organization and functional structure of the College of Engineering. This description provides a conceptual foundation for the development of the mathematical model that follows in later chapters. A comment by Stone (7) concerning model building seems appropriate at this time:

> ... we do not begin by building, or even trying to build, perfect models. We begin by modeling the main features of the system we are studying and then try to improve on our prototype. Generally speaking we can never continue this process to its end...

With this thought in mind, the first steps in modeling a complex system such as the College of Engineering are to study the fundamental structure of the College and to identify the basic functions it performs in the areas of instruction, research, and extension.

Organizational Structure

The organizational structure of the Division of Engineering is indicated in Figure 2. The Division of Engineering includes the College of Engineering, Engineering and Industrial Extension, Engineering Research, and the Technical Institutes (Stillwater and Oklahoma City).

The College of Engineering, which is composed of eight schools, is the focal point of this research. None of the other units that comprise the Division of Engineering will be studied. However, since the primary

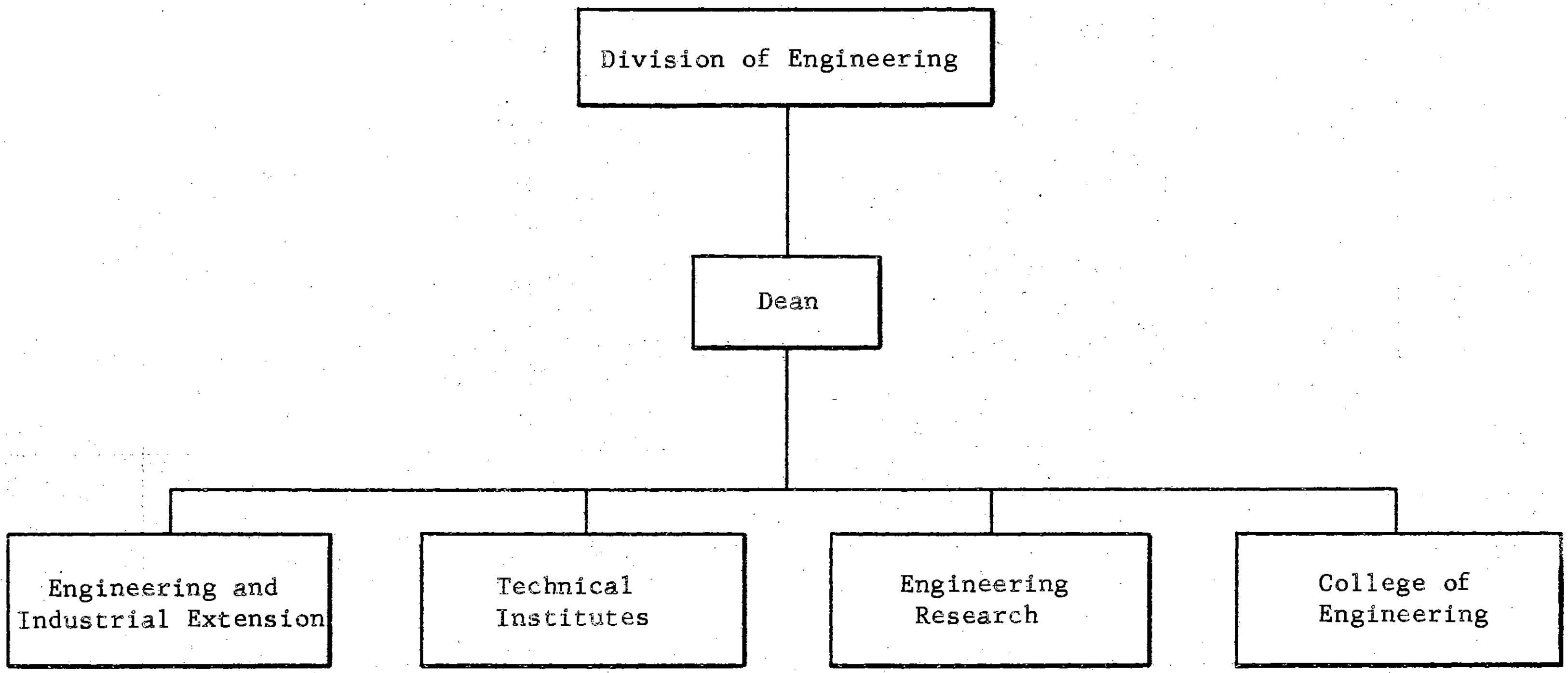


Figure 2. Organization of the Division of Engineering

function of Engineering and Industrial Extension and Engineering Research is to coordinate, respectively, extension and research work conducted mainly by the College of Engineering, it follows that the major effort of these units is implicit in the model of the College of Engineering.

The organizational structure of the College is indicated in Figure 3.

Conceptual Structure

It was mentioned previously in Chapter I that one of the best ways to approach the problem of modeling the College is to describe the administrative organization and the functions performed. With this in mind, the conceptual structure of the College of Engineering is shown in Figure 4. The College is considered to be composed of two sectors, i.e. a student sector and a production sector. Arrows directed towards a box in Figure 4 indicates inputs; whereas, arrows directed away from a box indicate outputs. All inputs and outputs are vector functions of time evaluated at discrete times.

The student sector accounts for the currently enrolled student population in the College and the inputs of credit hours of instruction demanded by this population.

The input vector labeled "Entering Students" denotes students who arrive from off-campus or transfer from other colleges on-campus and enroll in engineering. Off-campus arrivals include new high school graduates, readmitted students, and transfer students from junior colleges or other universities. The output vector labeled "Departing Students" denotes students departing the College, e.g., students who transfer to other colleges within the University, students who graduate, students

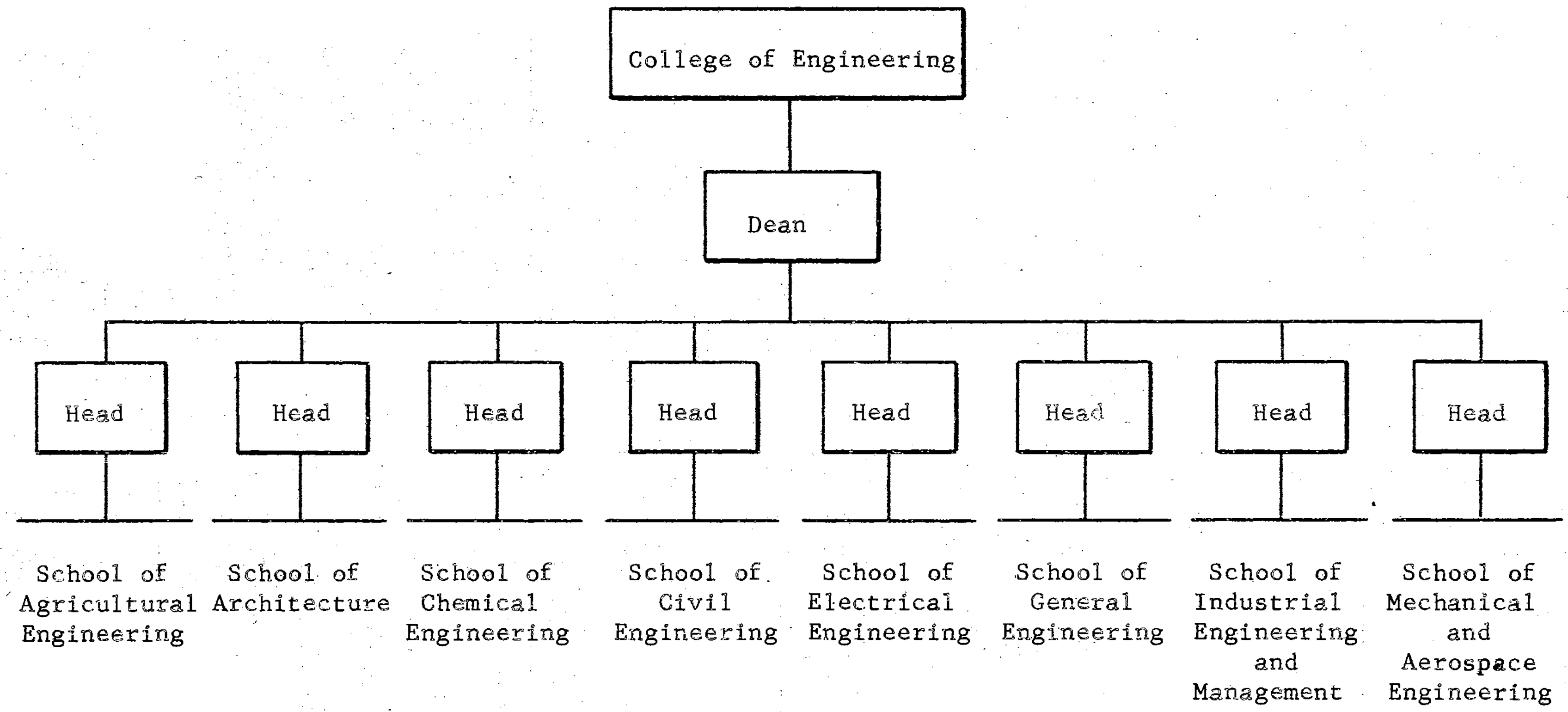


Figure 3. Organization of the College of Engineering

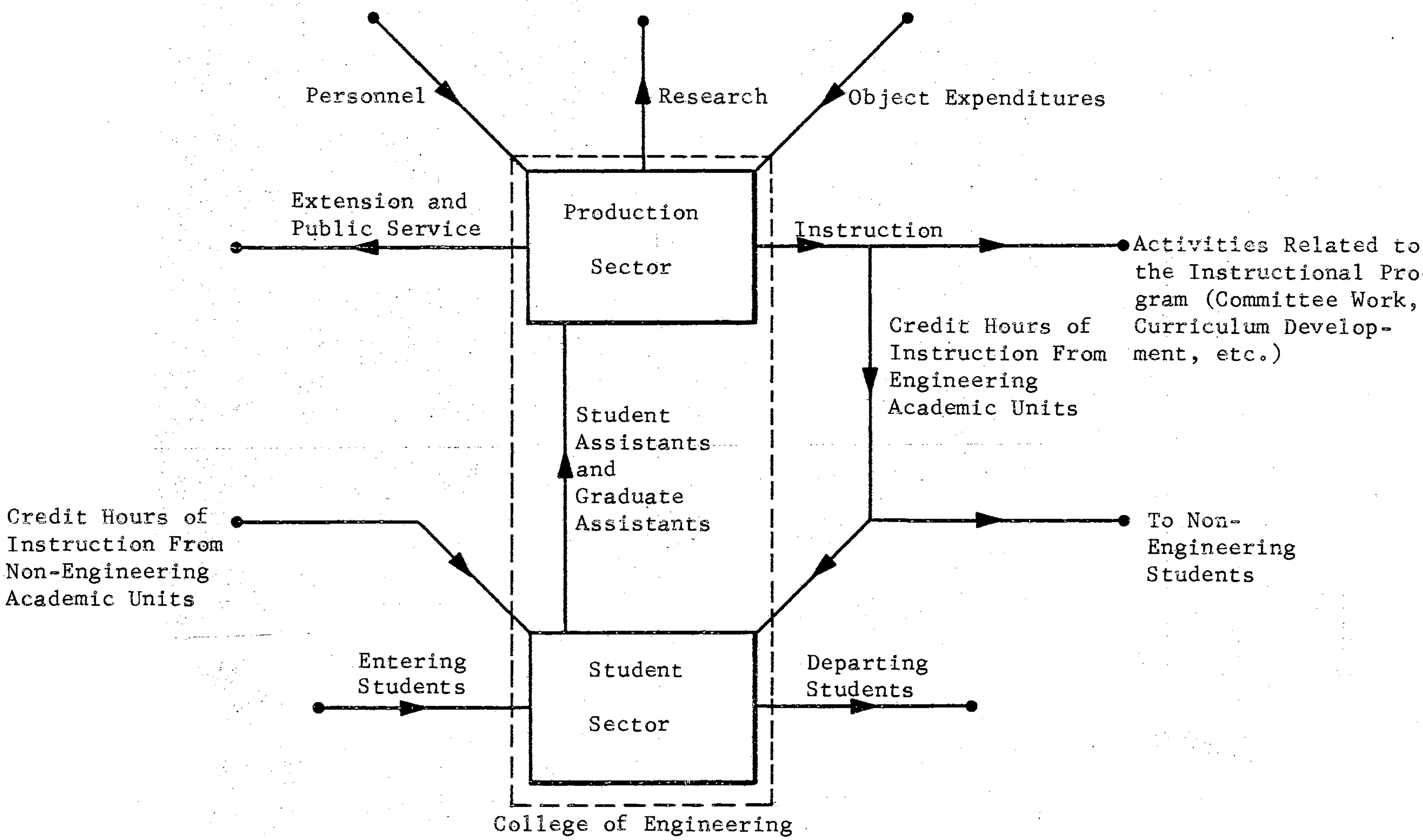


Figure 4. Conceptual Structure of the College of Engineering Including Functions Performed

who drop out, etc. The vector labeled "Credit Hours of Instruction From Non-Engineering Academic Units" denotes credit hours of instruction supplied to engineering students by non-engineering academic units on campus. Part of the vector "Credit Hours of Instruction From Engineering Academic Units" is an input to the student sector denoting credit hour demands imposed by students enrolled in the College. The remainder is "exported" to satisfy the demands imposed by non-engineering students. The output vector labeled "Student Assistants and Graduate Assistants" denotes the use of these assistants in the production sector.

The cost of credit hours of instruction taken by College students is based upon the resources used in producing them. If one knows the number of credit hours taken in a certain school at a specific level and can find their cost, then one can impute values to students receiving this instruction. The student sector model is designed to allow this evaluation.

The production sector shown in Figure 4 indicates, schematically, how the input resources of personnel, graduate and student assistants, and object expenditures are allocated to the three main production functions: instruction, research, and extension and public service. The "Personnel" input includes administrators, faculty and staff. "Object expenditures" denotes expenditures per time period for materials and supplies, equipment, and furniture, books and periodicals, communication, travel and other expenses paid for out of the College and school budgets. Indirect costs of the physical plant, library, etc. are not included. In order to simulate the allocation and flow of funds in the College, the model is formulated in such a way that funds allocated to a production unit (school) are distributed among the three primary functions of instruction, research, and extension. To avoid ambiguity in processing the costs and values (in dollars), it is necessary to establish a convention for the sign of these quantities. Thus, funds that are inputs to a production unit will be considered positive quantities and values received (output) from a production unit will be considered negative. For example, costs of student-credit-hours produced in the production sector are considered negative since they represent output costs, whereas, these same costs are considered positive inputs of the student sector.

The production sector then is structured in such a manner that resource allocation by each school in the College might be studied in detail.

CHAPTER IV

STUDENT SECTOR

Introduction

The internal states of the College system during the t^{th} time interval are described in terms of the student enrollment distribution in the College and the associated unit costs resulting from education provided to the College students. A student population model is developed that describes the student enrollment distribution of the College at time t as dependent upon students continuing in the College from the previous time period, the enrollment choices of new arrivals from off-campus, and the enrollment choices of transfers from on-campus. Variables that may influence student enrollment are introduced into the equations describing the student enrollment of the College. Included in the student population model is a set of equations describing student departures from the College.

The model of the student sector also describes student-credit-hour demands imposed upon the College by all University students, with distinction made between those demands imposed by engineering students and those demands imposed by non-engineering students. In addition, the model of the student sector describes the student-credit-hour demands imposed upon non-engineering academic units by all University students, with distinction made between those demands imposed by engineering students and those demands imposed by non-engineering students.

Finally, the student sector describes the average cost imputed to a student in the College determined from the costs of credit hours of education provided to a student at that point in time.

The t^{th} time interval (period) referred to in this report may be a semester, academic year, calendar year, or any other time interval convenient in terms of the data base available. In this report, the time interval refers to a semester or similar course enrollment period.

It should be pointed out that some features of the Michigan State University model have been incorporated in the model of the student sector. For example, the student population distribution in the Michigan State University model is described by a set of first-order difference equations. The concept of the internal state of the system is considered in the Michigan State University model, and control variables that may influence the student enrollment distribution are described. However, the model of the student sector described in this chapter also differs from the Michigan State University model in many respects. New variables and equations have been introduced; and others have been redefined, changed, or omitted in order to describe the College system. Certain new concepts have been introduced, and some concepts introduced in the Michigan State University model have been extended.

Student Population Model

A student population model that describes the movement of students through the system will be described next. Subsets within the student population are defined in terms of categories which are called "states". The states of the system provide a location for each student in the system. For example, "Electrical Engineering Freshman" describes one possible state into which students can be placed. In general, the categories (states) used in the student population model for the College of Engineering will be bivariate in nature, i.e. school and student level. There are exceptions, however. Since many freshmen and some sophomore students delay in declaring their majors, the categories "Engineering Freshman" and "Engineering Sophomore" are used to describe these students. Also, students who are not candidates for a degree are categorized as "Engineering Special".

The concept of state is extremely flexible. For example, one may consider all students who are enrolled in a particular school or college as states of the system. There are many other categories that could be selected to provide a location for each student in the system. However, in establishing the state definition, one must be aware of the rate of proliferation of the number of states. As an example, if one uses school and student level as categories, 47 states are defined for the College of Engineering, i.e. 8 schools (Agricultural Engineering, Architecture, Chemical Engineering, Civil Engineering, Electrical Engineering, General Engineering, Industrial Engineering and Management, and Mechanical and Aerospace Engineering), each with 6 student levels (Freshman, Sophomore, Junior, Senior, Master, and Doctor) except Architecture which has no Doctoral program. In addition to the 47 states defined above, Engineering Freshman, Engineering Sophomore, and Engineering Special are required to complete the description of the student population in the College of Engineering. The total number of states is 50 in this example.

If transitions from each of the states into any of the other states is allowed, a transition matrix with 2500 entries (50 x 50) is generated. It should be apparent that a set of states can be easily defined that will exceed a computer's storage capacity. In addition, if the states of the system are defined such that the number of students in certain states is small, projections for these states obtained from simulation will be statistically unreliable. The theoretical model will allow any number of states; but, in actual practice, the number of states is restricted due to computer processing time and limited storage capacity.

In order to keep the model flexible for adoption to other colleges, certain subscripts and superscripts used in the model are general in nature, e.g., N categories of student enrollment are defined rather than specifying a specific number of categories. Let the student population vector be defined as:

$$\underline{s}(t) = [s_i(t)]_{N\times 1} \tag{4.1}$$

where $s_i(t)$ represents the number of students in category i within the College of Engineering after enrollments are fixed at the beginning of the t^{th} time interval. Then $\underline{s}(t)$ can be expressed as a set of first-order difference equations that describe the changes in student enrollment from one time period to the next, i.e.

$$\underline{s}(t) = U(t)\underline{s}(t-1) + V(t)\underline{p}(t-1) + W(t)\underline{q}(t-1) \;. \tag{4.2}$$

In Equation 4.2, the matrix U(t) and vector $\underline{s}(t-1)$ are defined as:

$$U(t) = [u_{ij}(t)]_{N\times N} \tag{4.3}$$

and

$$\underline{s}(t-1) = [s_j(t-1)]_{N\times 1} \tag{4.4}$$

where $u_{ij}(t)$ represents the proportion of continuing College students that were in category j at time (t-1) and are in category i at time t and the components of $\underline{s}(t-1)$ represent the number of students, by category, that are enrolled in the College at time (t-1). $U(t)\underline{s}(t-1)$ then represents the number of students, by category, that were enrolled in the College at time (t-1) and are still enrolled in the College at time t.

In Equation 4.2, the matrix V(t) and vector $\underline{p}(t-1)$ are defined as:

$$V(t) = [v_{ij}(t)]_{NxN1} \quad (4.5)$$

and

$$\underline{p}(t-1) = [p_j(t-1)]_{N1x1} \quad (4.6)$$

where $v_{ij}(t)$ represents the proportion of new arrivals of type j that enroll in category i at time t and the components of $\underline{p}(t-1)$ represent the number of new arrivals from off-campus, by type, that are enrolled in the College at time t. $V(t)\underline{p}(t-1)$ then represents the number of new students, by category, that arrive from off-campus during time period (t-1) and are enrolled in the College at time t.

As an example, six possible components of $\underline{p}(t-1)$ are:

1. New high school graduates, non-resident of Oklahoma
2. New high school graduates, resident
3. Transfer students, non-resident
4. Transfer students, resident
5. Readmission students, non-resident
6. Readmission students, resident.

In this example N1=6; however, one can aggregate or disaggregate the types if desired.

The entries in each column of V(t) sum to one, i.e.

$$\sum_{i=1}^{N} v_{ij}(t) = 1, \qquad j=1,\ldots,N1 \quad . \tag{4.7}$$

In Equation 4.2, the matrix W(t) and vector $\underline{q}(t-1)$ are defined as:

$$W(t) = [w_{ij}(t)]_{NxN2} \tag{4.8}$$

and

$$\underline{q}(t-1) = [q_j(t-1)]_{N2x1} \tag{4.9}$$

where $w_{ij}(t)$ represents the proportion of on-campus transfers of type j that are enrolled in category i at time t and the components of $\underline{q}(t-1)$ represent the number of transfers from on-campus, by type, that are enrolled in the College at time t. $W(t)\underline{q}(t-1)$ then represents the number of transfer students from on-campus, by category, that transfer into the College during time period (t-1) and are enrolled in the College at time t.

Seven possible origins of transfer are:

1. College of Agriculture
2. College of Arts and Sciences
3. College of Business
4. College of Education
5. College of Home Economics
6. College of Veterinary Medicine
7. Technical Institute (Stillwater).

In this example N2=7; however, one can break down the types of transfers even further, e.g., one may desire to analyze transfers from particular departments outside the College of Engineering.

The entries in each column of W(t) sum to one, i.e.

$$\sum_{i=1}^{N} w_{ij}(t) = 1, \qquad j=1,\ldots,N2 \quad . \qquad (4.10)$$

In brief, Equation 4.2 describes the student enrollment distribution of the College at time t as dependent, respectively, upon students continuing from the previous time period, the enrollment choices of new arrivals from off-campus, and the enrollment choices of transfers from on-campus.

The transitions, arrivals, and transfers described in Equation 4.2 are influenced by many variables, e.g., the decisions or behavior of students, availability of financial aid, grade point requirements, etc. It should be possible to isolate certain factors that influence the transitions, arrivals, and transfers described in Equation 4.2. If factors that are subject to control are isolated, they may be regarded as control variables of the system. As an example of a first step toward identifying controls, Koenig et al. (14) assume that the number of fellowships and graduate assistantships available will affect the number of students continuing with or beginning graduate work. They also point out that the availability of scholarships or tuition discounts in particular areas may affect the decisions of undergraduates as well.

Financial aid to students exists in various forms, e.g., scholarships, fellowships, traineeships, awards, grants, assistantships, loans, etc. Financial help is certainly one factor that affects student transitions, arrivals, and transfers. To illustrate how financial aid in the form of graduate assistantships and student assistantships (normally awarded at the discretion of the individual schools in the College) might be considered control variables, two vectors are introduced into the model, i.e.

$$\underline{g}(t) = [g_j(t)]_{A1x1} \tag{4.11}$$

and

$$\underline{u}(t) = [u_j(t)]_{A2x1} \quad . \tag{4.12}$$

The entries $g_j(t)$ and $u_j(t)$ represent, respectively, the number of full-time-equivalent graduate and student assistantships awarded of school-type j to students enrolled in the College during time t.

Graduate assistantships may be classified as graduate teaching assistantships and graduate research assistantships, according to graduate student levels, aggregated into one classification of graduate assistantships, etc. Student assistantships may be classified according to undergraduate student levels, aggregated into one classification of student assistantships, etc.

Equation 4.2 is now modified by writing

$$\underline{s}(t) = T(t)\underline{s}(t-1) + Q(t)\underline{p}(t-1) + X(t)\underline{q}(t-1) + H\underline{g}(t) + J\underline{u}(t) \tag{4.13}$$

where H is an NxA1 and J is an NxA2 matrix relating, respectively, the number of students served by the number of full-time-equivalent graduate assistantships and student assistantships awarded. One full-time-equivalent assistantship may provide financial help to 8 students working 1/8 time, 4 students working 1/4 time, 2 students working 1/2 time, etc. The matrices T(t), Q(t), and X(t) in Equation 4.13 are modified versions, respectively, of U(t), V(t), and W(t) in Equation 4.2. Modifications of

U(t), V(t), and W(t) are required to remove, respectively, the transitions, arrivals, and transfers of students awarded graduate and student assistantships by the College.

The concept of financial aids as control variables brings up several points of interest. For example, consider a particular school in the College operating under a fixed budget. It may be important for school administrators to identify those students who deserve and require financial aid in the form of graduate assistantships and student assistantships. If these students are identified and the minimum amount of aid determined, administrators should be able to do a better job of awarding assistantships than would be the case if no information were available. If assistantships are awarded on a "first-come, first-served" basis, some students may have to leave the University or transfer to another department that offers assistantships.

In brief, College administrators may influence the student enrollment distribution by increasing or decreasing the ratio of students served per full-time-equivalent assistantship or by increasing or decreasing the number of full-time-equivalent assistantships awarded. If the policy of the school is to aid as many of its students as possible within the limitations imposed by a fixed budget and school requirements, a survey of its students may be in order.

Other variables which influence or control student enrollments may be included in the model if they can be represented by quantitative vectors and if their influence can be measured.

How does one determine the number of students of all categories that depart from the College during or at the end of time period (t-1)? It follows from Equation 4.3 that the sum

$$\sum_{i=1}^{N} u_{ij}(t)$$

represents the total proportion of the students in category j at time (t-1) that still remain in the College at time t. The difference

$$z_j(t) = 1 - \sum_{i=1}^{N} u_{ij}(t) \tag{4.14}$$

represents the proportion of students of category j who depart from the College during time period (t-1). The departure of a student from the College does not necessarily mean that the student has departed the University. He may have transferred to a non-engineering academic department on campus.

A set of equations of the form

$$\underline{d}(t) = Z(t)\underline{s}(t-1) \tag{4.15}$$

may be written to describe student departures from the College, by category. Z(t) is an NxN diagonal matrix whose j^{th} diagonal element is $z_j(t)$.

Administrators may be interested in knowing why students depart the College. This provision is introduced into the model in the following manner. Let

$$\underline{v}(t) = [v_i(t)]_{N3x1} \tag{4.16}$$

represent the number of students departing from the College, by reason, during time period (t-1). Then $\underline{v}(t)$ can be expressed as:

$$\underline{v}(t) = D(t)\underline{s}(t-1) \tag{4.17}$$

where

$$D(t) = [d_{ij}(t)]_{N3xN} \qquad (4.18)$$

and $d_{ij}(t)$ represents the proportion of students in category j at time (t-1) who do not enroll in the College at time t due to reason i. Students may depart the College due to graduation, grade point deficiency, illness, death, transfer to another college or university, transfer to another department on campus, accident, financial difficulty, etc. Whatever the reason for departure, an accounting should be made for each student who departs the College. If a student simply drops out for no apparent reason, a follow-up questionnaire should be used to determine the reason(s) for dropping out. Otherwise, the student is simply listed as a dropout.

An analysis of student departures from the College should be helpful to administrators concerned with student retention. Equation 4.17 can be used to answer such questions as: "How many students transferred from the College of Engineering to other colleges of the University?"; "How many Electrical Engineering freshmen transferred to the College of Arts and Sciences?"; "How do these figures compare to those of previous time periods?" These are only a few of the questions that could be answered. In addition, the net transfer gain or loss for the various student categories in the College can be determined by comparing transfers into the College obtained from $W(t)\underline{q}(t-1)$ in Equation 4.2 with appropriate transfers out of the College obtained from Equation 4.17.

Student Demand Equations

Students in the College impose demands upon the College for credit hours of course work as well as demands for certain types of services such as counseling and advisement. If the academic program of the student includes research effort, demands are made upon the faculty to provide guidance of the research effort. No distinction is made in the model between credit hours associated with course work and thesis credit hours. However, the difference in cost of instruction for course work and thesis advisement will be taken into account in Chapter V.

Let

$$\underline{c}(t) = [c_i(t)]_{N4x1} \tag{4.19}$$

represent the student-credit-hour demands during time period t, by school and course level, imposed by all students in the University upon the College. Then $\underline{c}(t)$ can be expressed as:

$$\underline{c}(t) = C\underline{s}(t) + \Phi\underline{x}(t) \tag{4.20}$$

where

$$C = [c_{ij}]_{N4xN} \tag{4.21}$$

and c_{ij} represents the average number of credit hours from school-course level i taken by a student enrolled in category j of the College. The product $C\underline{s}(t)$ represents the student-credit-hour demands, by school and course level, imposed upon the College by its own students during time period t.

In Equation 4.20,

$$\Phi = [\phi_{ij}]_{N4x5} \tag{4.22}$$

and

$$\underline{x}(t) = [x_j]_{N5x1} \tag{4.23}$$

where ϕ_{ij} represents the average number of credit hours from school-course level i taken by a non-engineering student enrolled in category j (academic area and student level) of the University and the components of the vector $\underline{x}(t)$ represent non-engineering student enrollment, by academic area and student level. The product $\Phi\underline{x}(t)$ then represents the student-credit-hour demands, by school and course level, imposed upon the College by non-engineering students.

It might be desirable to consider the origins of student transfers into the College from on-campus as being identical to the population states describing non-engineering student enrollment. In this case, N2 in Equation 4.9 is equal to N5 in Equation 4.23.

Course levels may be designated as freshman, sophomore, junior, senior, master, and doctor. In some cases, course levels might be designated as lower-division undergraduate (1000 and 2000 level courses), upper-division undergraduate (3000 and 4000 level courses), and graduate (5000 and 6000 level courses). Obviously, depending upon the detail desired, there are other choices that one can use in describing course levels, e.g., undergraduate and graduate. One can also describe student-credit-hour demands by student levels rather than by course levels. Let

$$\underline{o}(t) = [o_i(t)]_{N6x1} \tag{4.24}$$

represent the student-credit-hour demands, by academic unit and course level, imposed upon non-engineering academic units by all students in the University. Then $\underline{o}(t)$ can be expressed as:

$$\underline{o}(t) = M\underline{s}(t) + N\underline{x}(t) \tag{4.25}$$

where

$$M = [m_{ij}]_{N6xN} \tag{4.26}$$

and m_{ij} represents the average number of credit hours from non-engineering academic unit-course level i taken by a student enrolled in category j of the College. The product $M\underline{s}(t)$ represents the student-credit-hour demands, by academic unit and course level, imposed upon non-engineering academic units by students enrolled in the College.

In Equation 4.25,

$$N = [n_{ij}]_{N6xN5} \tag{4.27}$$

where n_{ij} represents the average number of credit hours taken from non-engineering academic unit-course level i by a non-engineering University student enrolled in category j of the University. The product $N\underline{x}(t)$ then represents the student-credit-hour demands, by academic unit and course level, imposed upon non-engineering academic units by non-engineering students. From Equations 4.20 and 4.25,

$$\begin{bmatrix} \underline{c}(t) \\ \underline{o}(t) \end{bmatrix} = \begin{bmatrix} C \\ M \end{bmatrix} \underline{s}(t) + \begin{bmatrix} \Phi \\ N \end{bmatrix} \underline{x}(t) = K\underline{s}(t) + L\underline{x}(t) \tag{4.28}$$

where

$$K = \begin{bmatrix} C \\ M \end{bmatrix}_{(N4+N6)xN} = \begin{bmatrix} k_{ij} \end{bmatrix}_{N7xN} \tag{4.29}$$

and

$$L = \begin{bmatrix} \Phi \\ N \end{bmatrix}_{(N4+N6)xN5} = \begin{bmatrix} \ell_{ij} \end{bmatrix}_{N7xN5} . \qquad (4.30)$$

The j^{th} column sum of K, i.e.

$$\sum_{i=1}^{N7} k_{ij}$$

gives the average credit hour demands imposed upon all academic production units of the University by a student enrolled in category j of the College.

Similarly, the j^{th} column sum of L, i.e.

$$\sum_{i=1}^{N7} \ell_{ij}$$

gives the average credit hour demands imposed upon all academic production units of the University by a student enrolled in category j of the University.

Equation 4.28 can be used to calculate the full-time-equivalent student enrollment of a particular category, a school, the College of Engineering, the University, etc. For example, suppose that the full-time-equivalent student enrollment for category 5 of the College is desired, and let category 5 represent master degree students in Industrial Engineering. From Equation 4.28, the total number of student-credit-hours taken by students enrolled in category 5 of the College is:

$$\sum_{i=1}^{N7} k_{i5} \, s_5(t) = \mathcal{S}_5 \qquad (4.31)$$

where $\mathcal{S}_5$ denotes sum. The full-time-equivalent student enrollment for category 5 is obtained by dividing $\mathcal{S}_5$ by 12.

In a self-study of higher education in Oklahoma published in 1964, FTE (full-time-equivalent) student enrollment was one statistic used in projecting needs for phsycial plant space (15). For example, a standard of five assignable square feet per FTE student was used in projecting needs for Administration and General space.

Educational Costs

College and University administrators may be interested in knowing the unit cost, in dollars, of educating students. This provision is included in the model and allows one to impute educational costs to students enrolled in various categories of the College of Engineering. The development that follows is intended as a starting point in answering such questions as: "What is the average cost involved in producing a Bachelor's, Master's, or Doctor's degree in a given school of the College?"; "What is the average cost involved in educating a student that is designated a freshman, sophomore, junior, or senior in a given school of the College?"

Suppose that one desires to impute an educational value (cost) to each student in the College. The educational value imputed to the student at the end of the t^{th} time period is equal to the educational value of the student at the end of the $(t-1)^{th}$ time period plus the value of credit hours taken by the student during time period t. One could determine the educational value of each individual student in the College; however, the following development considers average imputed values of students enrolled in the College, by category.

Let

$$\underline{\hat{s}}(t) = [\hat{s}_i(t)]_{Nx1} \tag{4.32}$$

be a subvector of the state vector whose components, $\hat{s}_i(t)$, represent the average cost or imputed unit value (dollars per student) of education received by a student enrolled in category i of the College. Let

$$\underline{\hat{\ell}}(t) = [\hat{\ell}_i(t)]_{Nx1} \tag{4.33}$$

represent the unit values (dollars per student) of credit hours taken, by category, during time period t by students enrolled in the College. Then $\underline{\hat{\ell}}(t)$ can be expressed as:

$$\underline{\hat{\ell}}(t) = C^T\underline{\hat{c}}(t) + M^T\underline{\hat{o}}(t) \tag{4.34}$$

where $\underline{\hat{c}}(t)$ and $\underline{\hat{o}}(t)$ are the unit costs (dollars per student-credit-hour), respectively, of $\underline{c}(t)$ and $\underline{o}(t)$. C^T and M^T (credit hours) are the transposes, respectively, of C and M in Equation 4.28.

Before proceding further, the reader is referred to Equation 4.2 which describes the student enrollment distribution of the College at time t in terms of the students continuing in the College from the previous time period, the enrollment choices of new arrivals from off-campus, and the enrollment choices of transfers from on-campus. Using the notation described in Equation 4.2, let

$$y_{ij}^u(t) = \frac{u_{ij}(t)s_j(t-1)}{s_i(t)} \tag{4.35}$$

$$y_{ij}^v(t) = \frac{v_{ij}(t)p_j(t-1)}{s_i(t)} \tag{4.36}$$

$$y^{w}_{ij}(t) = \frac{w_{ij}(t)q_j(t-1)}{s_i(t)} \tag{4.37}$$

represent, respectively, the proportions of students entering category i from category j of continuing students, arrivals from off-campus, and transfers from on-campus. Then the educational value imputed to a student in category i of the College during the t^{th} time interval can be expressed as a weighted average of the values imputed to continuing students who enter category i from other categories (or remain in category i), the values imputed to new arrivals from off-campus that enter category i, and the values imputed to transfers from on-campus that enter category i. Added to this weighted average is the unit value of credit hours taken by category i students during the t^{th} time period. The education value imputed to a student in category i of the college is:

$$\hat{s}_i(t)=\sum_{j=1}^{N} y^{u}_{ij}(t)\hat{s}_j(t-1)-\sum_{j=1}^{N1} y^{v}_{ij}(t)\hat{p}_j(t-1)-\sum_{j=1}^{N2} y^{w}_{ij}(t)\hat{q}_j(t-1)-\hat{\ell}_i(t) \quad . \tag{4.38}$$

The average imputed values for all student categories in the College is written as:

$$\underline{\hat{s}}(t) = Y^{u}(t)\underline{\hat{s}}(t-1) - Y^{v}(t)\underline{\hat{p}}(t-1) - Y^{w}(t)\underline{\hat{q}}(t-1) - C^{T}\underline{\hat{c}}(t) - M^{T}\underline{\hat{o}}(t) \tag{4.39}$$

where

$$Y^{u}(t) = [y^{u}_{ij}(t)]_{NxN} \tag{4.40}$$

$$Y^{v}(t) = [y^{v}_{ij}(t)]_{NxN1} \tag{4.41}$$

$$Y^{w}(t) = [y^{w}_{ij}(t)]_{NxN2} \tag{4.42}$$

and $\hat{\underline{s}}(t-1)$, $\hat{\underline{p}}(t-1)$, and $\hat{\underline{q}}(t-1)$ represent, respectively, the values imputed to students continuing in the College, arrivals from off-campus, and transfers from on-campus measured at the end of time period (t-1).

The components of $\hat{\underline{s}}(t)$ are negative numbers representing unit costs of output of the student sector. Unit values of credit hours taken, imputed values of arrivals from off-campus, and imputed values of transfers from on-campus are positive numbers representing inputs to the student sector.

Those categories in $\hat{\underline{p}}(t-1)$ that represent imputed values of new high school graduates could be assigned zero values. One might assume, initially, that the imputed values of the other arrivals from off-campus are the same as the corresponding values of students enrolled in the College. In order to determine $\hat{\underline{q}}(t-1)$, non-engineering academic areas must supply the imputed values of their students that transfer into the College.

From Equations 4.1 and 4.32, the state vector, $\underline{s}_1(t)$, is obtained, i.e.,

$$\underline{s}_1(t) = \begin{bmatrix} \underline{s}(t) \\ \\ \hat{\underline{s}}(t) \end{bmatrix}_{2N\times 1} \quad . \tag{4.43}$$

CHAPTER V

PRODUCTION SECTOR

Introduction

The model of the student sector developed in Chapter IV describes student demands for credit hours of instruction from the College. Student demands for these credit hours are met by production units (schools) of the College. The word "production" is broadly interpreted and does not imply that the College of Engineering is a production enterprise similar to a factory. However, the College of Engineering does exist to render services and the fulfillment of these services is a definite form of production.

In addition to student demands for credit hours of instruction, the College is expected to meet more general demands for other services, such as sponsored research and public service.

This chapter describes the model which has been formulated to simulate the allocation of resources by the College to perform its three main functions: instruction, research, and extension.

The model allows simulation of the policies followed by the administration in funding certain operational activities. Model parameters describe, for example, such ratios as the FTE (full-time-equivalent) faculty (by rank) per student-credit-hour produced (by school and course level). The resource allocation policies are, theoretically, within the control of the administration. Presumably, the mix of resources results in high quality products. Quality of educational services or functions can be inferred from such quantitative factors as the ratio of students to faculty, square feet of classroom and laboratory facilities per student, educational and general purpose funds available per student, etc. The development of a mathematical expression that relates quality to these factors is, however, beyond the scope of this research.

The description of the production sector includes the unit costs of production determined from the number of personnel utilized, the object expenditures per time period, unit costs of personnel, and the numbers of units produced.

Because of the use of student assistants and graduate assistants in the production sector, each school is considered to have "feedback loops" from the student population through which part of the production requirements are supplied.

The schools of the College are described in terms of input-output models. "Input" refers to personnel effort, supply and equipment expenditures, etc. "Output" refers to student-credit-hours produced, man-hours of research produced, etc. In the development that follows, M1 production units (schools) are defined.

The resources utilized within the schools in production during time period t will be described next. The vector

$$\underline{a}^{ij}(t) = [a_m^{ij}(t)]_{M^{j2} x1} \qquad (5.1)$$

represents the number of FTE units of individual administrative effort utilized in school j on sub-function i during the t^{th} time period. Each entry $a_m^{ij}(t)$ corresponds to a single administrator employed by school j. Faculty, staff, graduate assistant, and student assistant effort (measured in FTE units) utilized in school j on sub-function i during the t^{th} time period is similarly defined. Let

$$\underline{f}^{ij}(t) = [f_m^{ij}(t)]_{M^{j3}x1} \qquad (5.2)$$

represent faculty effort with M^{j3} faculty members identified; let

$$\underline{r}^{ij}(t) = [r_m^{ij}(t)]_{M^{j4}x1} \qquad (5.3)$$

represent staff effort with M^{j4} staff members identified; let

$$\underline{g}^{ij}(t) = [g_m^{ij}(t)]_{M^{j5}x1} \qquad (5.4)$$

represent graduate assistant effort with M^{j5} graduate assistants identified; and let

$$\underline{u}^{ij}(t) = [u_m^{ij}(t)]_{M^{j6}x1} \qquad (5.5)$$

represent student assistant effort with M^{j6} student assistants identified. It should again be noted that each entry of these vectors is identified with an individual employee. Thus

$$\sum_{k=2}^{6} M^{jk} = \text{total number of individuals employed by school j.}$$

Now let

$$\underline{e}^{ij}(t) = [e_m^{ij}(t)]_{M^{j7}x1} \qquad (5.6)$$

represent object expenditures (dollars) per time period, with M^{j7} categories of object expenditures identified, expended by school j during the t^{th} time period.

In the development that follows, the notation defined by Equations 5.1 - 5.6 with consistent units will be used. However, the size of the vectors will later be changed in order to aggregate and superscripts on the vectors will change to indicate sub-functions, course levels, courses, activities, projects, etc.

Instruction

The credit hours of instruction demanded from the College by all students in the University are produced by the schools of the College. In the model, the number of student-credit-hours produced by a school at a particular course level is equivalent to the student demand for instruction from the school at the particular course level. While student demand is not the sole educational criterion for maintaining instruction in a school at a particular course level, it should be one of the factors considered by an institution in acting on proposals to expand (or restrict) course offerings.

In the model, the function of instruction is broken down into two sub-functions which are described as:

1. The on-campus credit course program
2. Activities related to the on-campus instructional program.

In order to show individual employee effort and object expenditures in the production of student-credit-hours in each course, let the input-output model of the j^{th} production unit (school) for the on-campus credit course program be represented by Equation 5.7.

The superscripts 1 and j on the inputs denote, respectively, on-campus credit course program and school j. The superscripts on the

$$
\begin{array}{r}
\text{Administrative Effort} \\ \\ \\
\text{Faculty Effort} \\ \\ \\
\text{Staff Effort} \\ \\ \\
\text{Graduate Assistant Effort} \\ \\ \\
\text{Student Assistant Effort} \\ \\ \\
\text{Object Expenditures}
\end{array}
\left\{
\underbrace{\begin{bmatrix}
\underline{a}^{1j}(t) \\ \\ \\
\underline{f}^{1j}(t) \\ \\ \\
\underline{r}^{1j}(t) \\ \\ \\
\underline{g}^{1j}(t) \\ \\ \\
\underline{u}^{1j}(t) \\ \\ \\
\underline{e}^{1j}(t)
\end{bmatrix}}_{\text{Inputs}}
\right.
=
\underbrace{\left[\begin{array}{cc:cc:c:cc}
A^{1j11} \ldots & A^{1j1N_{j1}} & A^{1j21} \ldots & A^{1j2N_{j2}} & \ldots & A^{1j61} \ldots & A^{1j6N_{j6}} \\ \\ \\
F^{1j11} \ldots & F^{1j1N_{j1}} & F^{1j21} \ldots & F^{1j2N_{j2}} & \ldots & F^{1j61} \ldots & F^{1j6N_{j6}} \\ \\ \\
R^{1j11} \ldots & R^{1j1N_{j1}} & R^{1j21} \ldots & R^{1j2N_{j2}} & \ldots & R^{1j61} \ldots & R^{1j6N_{j6}} \\ \\ \\
G^{1j11} \ldots & G^{1j1N_{j1}} & G^{1j21} \ldots & G^{1j2N_{j2}} & \ldots & G^{1j61} \ldots & G^{1j6N_{j6}} \\ \\ \\
P^{1j11} \ldots & P^{1j1N_{j1}} & P^{1j21} \ldots & P^{1j2N_{j2}} & \ldots & P^{1j61} \ldots & P^{1j6N_{j6}} \\ \\ \\
E^{1j11} \ldots & E^{1j1N_{j1}} & E^{1j21} \ldots & E^{1j2N_{j2}} & \ldots & E^{1j61} \ldots & E^{1j6N_{j6}}
\end{array}\right]}_{\text{Input-Output Matrices}}
\underbrace{\left[\begin{array}{c}
c^{j11}(t) \\ \vdots \\ c^{j1N_{j1}}(t) \\ \hdashline
c^{j21}(t) \\ \vdots \\ c^{j2N_{j2}}(t) \\ \hdashline
\vdots \\ \hdashline
c^{j61}(t) \\ \vdots \\ c^{j6N_{j6}}(t)
\end{array}\right]}_{\text{Outputs}}
\begin{array}{l}
\left.\vphantom{\begin{array}{c}1\\1\\1\end{array}}\right\}\text{Level 1} \\
\left.\vphantom{\begin{array}{c}1\\1\\1\end{array}}\right\}\text{Level 2} \\
\\
\left.\vphantom{\begin{array}{c}1\\1\\1\end{array}}\right\}\text{Level 6}
\end{array}
\qquad (5.7)
$$

input-output matrices, from left to right, denote on-campus credit course program, school j, course level and course (N_{jk}, k=1,...,6 courses are identified in school j at course level k). For the output vectors, the superscripts from left to right denote school j, course level, and course. There are M^{j2} components in the vector $\underline{a}^{1j}(t)$ and each component represents the FTE effort of an individual administrator in school j involved in the on-campus credit course program. Similarly, there are M^{j3}, M^{j4}, M^{j5}, and M^{j6} individuals identified, respectively, in the vectors $\underline{f}^{1j}(t)$, $\underline{r}^{1j}(t)$, $\underline{g}^{1j}(t)$, and $\underline{u}^{1j}(t)$ and each component of these vectors represents the FTE effort of an individual. M^{j7} categories of object expenditures are identified in $\underline{e}^{1j}(t)$.

The input-output matrices $A^{1jkN_{jk}}$, $F^{1jkN_{jk}}$, $R^{1jkN_{jk}}$, $G^{1jkN_{jk}}$, and $P^{1jkN_{jk}}$ are measured in FTE units per student-credit-hour produced, whereas, $E^{1jkN_{jk}}$ has the units of dollars per student-credit-hour produced.

The typical entry $c^{j11}(t)$ of the output vector represents the number of student-credit-hours produced in school j, course level 1, course 1.

Equation 5.7 can also be written in the more compact form:

$$\begin{bmatrix} \underline{a}^{1j}(t) \\ \underline{f}^{1j}(t) \\ \underline{r}^{1j}(t) \\ \underline{g}^{1j}(t) \\ \underline{u}^{1j}(t) \\ \underline{e}^{1j}(t) \end{bmatrix} = \left[\begin{array}{c|c|c|c} S^{1j11}\dots S^{1j1N_{j1}} & S^{1j21}\dots S^{1j2N_{j2}} & \dots & S^{1j61}\dots S^{1j6N_{j6}} \end{array} \right] \left[\begin{array}{c} c^{j11}(t) \\ \circ \\ \circ \\ \circ \\ c^{j1N_{j1}}(t) \\ \hline c^{j21}(t) \\ \circ \\ \circ \\ \circ \\ c^{j2N_{j2}}(t) \\ \hline \circ \\ \circ \\ \circ \\ \hline c^{j6N_{j6}}(t) \\ \circ \\ \circ \\ \circ \\ c^{j6N_{j6}}(t) \end{array} \right] \qquad (5.8)$$

where

$$S^{1jkN_{jk}} = [A^{1jkN_{jk}}, F^{1jkN_{jk}}, \ldots, E^{1jkN_{jk}}]^T$$

and T denotes the transpose.

Administrators concerned with undesirable course proliferation might desire to determine student-credit-hour costs for individual courses. These costs can be expressed directly in terms of the cost of the resources utilized. The costs per student-credit-hour in school j for each individual course is written as:

$$\begin{bmatrix} \hat{c}^{j11}(t) \\ \vdots \\ \hat{c}^{j1N_{j1}}(t) \\ \hline \hat{c}^{j21}(t) \\ \vdots \\ \hat{c}^{j2N_{j2}}(t) \\ \hline \vdots \\ \hline \hat{c}^{j61}(t) \\ \vdots \\ \hat{c}^{j6N_{j6}}(t) \end{bmatrix} = - \left[S^{1j11} \ldots S^{1j1N_{j1}} \,\middle|\, S^{1j21} \ldots S^{1j2N_{j2}} \,\middle|\, \ldots \,\middle|\, S^{1j61} \ldots S^{1j6N_{j6}} \right]^T \begin{bmatrix} \underline{\tilde{a}}^j(t) \\ \underline{\tilde{f}}^j(t) \\ \underline{\tilde{r}}^j(t) \\ \underline{\tilde{g}}^j(t) \\ \underline{\tilde{u}}^j(t) \\ \underline{i}^j(t) \end{bmatrix} . \tag{5.9}$$

where, for example, the entry $\hat{c}^{j11}(t)$ represents the unit cost (dollars per student-credit-hour) in school j, course level 1, and course 1; $\underline{\tilde{a}}^j(t)$, $\underline{\tilde{f}}^j(t)$, $\underline{\tilde{r}}^j(t)$, $\underline{\tilde{g}}^j(t)$, and $\underline{\tilde{u}}^j(t)$ are the unit costs (dollars per FTE), respectively of individual employees identified in school j; $\underline{i}^j(t)$ is a vector of 1's (dimensionless), i.e.

$$\underline{i}^j(t) = [1]_{M^{j7} x1} \qquad (5.10)$$

and the input-output matrices are those defined in Equation 5.8.

Since the student-credit-hour costs described by Equation 5.9 are output costs of the production sector, the values are defined to be negative. Note that the total cost of producing all student-credit-hours in school j during time period t can be determined easily from the scalar (inner) product

$$\begin{bmatrix} c^{j11}(t) \\ \vdots \\ c^{j1N_{j1}}(t) \\ \hdashline c^{j21}(t) \\ \vdots \\ c^{j2N_{j2}}(t) \\ \hdashline \vdots \\ \hdashline c^{j61}(t) \\ \vdots \\ c^{j6N_{j6}}(t) \end{bmatrix}^T \begin{bmatrix} \hat{c}^{j11}(t) \\ \vdots \\ \hat{c}^{j1N_{j1}}(t) \\ \hdashline \hat{c}^{j21}(t) \\ \vdots \\ \hat{c}^{j2N_{j2}}(t) \\ \hdashline \vdots \\ \hdashline \hat{c}^{j61}(t) \\ \vdots \\ \hat{c}^{j6N_{j6}}(t) \end{bmatrix} .$$

It follows that the total administrative, faculty, staff, graduate assistant, and student assistant costs may be determined in a similar manner, e.g., the scalar product of $\underline{f}^{1j}(t)$ and $\underline{\tilde{f}}^{j}(t)$ determines the total cost of faculty utilized in the on-campus credit course program of school j during time period t. The total cost for object expenditures for the on-campus credit course program of school j during time period t is determined by summing the column entries of $\underline{e}^{1j}(t)$, defined by Equation 5.6, i.e.

$$\sum_{m=1}^{M^{j7}} e_m^{1j}(t) \qquad .$$

A computer program has been written to demonstrate the method of calculating input vectors and student-credit-hour costs for individual courses indicated by Equations 5.7 and 5.9. A description of this program and a listing are given in the Appendix.

In many cases administrators, faculty, staff, and employed students devote man-hours to activities related to the instructional program but not directly in support of a specific course or course level. Such activities include meetings, committee work, general student advisement and correspondence. To properly allocate such personnel effort and certain related object expenditures in school j, the following system of equations is proposed:

$$\text{Resources}\left\{\begin{bmatrix} \underline{a}^{2j}(t) \\ \underline{f}^{2j}(t) \\ \underline{r}^{2j}(t) \\ \underline{g}^{2j}(t) \\ \underline{u}^{2j}(t) \\ \underline{e}^{2j}(t) \end{bmatrix}\right. = \left.\underbrace{\begin{bmatrix} A^{2j1} & \ldots & A^{2jM_j} \\ F^{2j1} & \ldots & F^{2jM_j} \\ R^{2j1} & \ldots & R^{2jM_j} \\ G^{2j1} & \ldots & G^{2jM_j} \\ P^{2j1} & \ldots & P^{2jM_j} \\ E^{2j1} & \ldots & E^{2jM_j} \end{bmatrix}}_{\text{Input-Output Matrices}} \underbrace{\begin{bmatrix} b^{j1}(t) \\ \\ \cdot \\ \cdot \\ \cdot \\ b^{jM_j}(t) \end{bmatrix}}_{\text{Outputs}}\right\}\text{Activities} \quad (5.11)$$

(Under the left column vector: Inputs)

where the superscripts 2 and j denote, respectively, those miscellaneous activities related to on-campus instruction and school j. The third superscript, 1, 2, ..., M_j denotes that there are M_j types of miscellaneous activities in school j. The typical entry $b^{j1}(t)$ represents the man-hours devoted to M_j types of activities in school j during the t^{th} time period. Note that Equation 5.11 is of the same form as Equation 5.7. The primary difference lies in the distinction of course levels in Equation 5.7 which requires an additional superscript.

In terms of the resources utilized and resource costs, the unit costs of producing man-hours of effort for activities related to the on-campus instruction program in school j during time period t are:

$$\begin{bmatrix} \hat{b}^{j1}(t) \\ \cdot \\ \cdot \\ \cdot \\ \hat{b}^{jM_j}(t) \end{bmatrix} = - \begin{bmatrix} A^{2j1} & \ldots & A^{2jM_j} \\ F^{2j1} & \ldots & F^{2jM_j} \\ R^{2j1} & \ldots & R^{2jM_j} \\ G^{2j1} & \ldots & G^{2jM_j} \\ P^{2j1} & \ldots & P^{2jM_j} \\ E^{2j1} & \ldots & E^{2jM_j} \end{bmatrix}^T \begin{bmatrix} \underline{\tilde{a}}^j(t) \\ \underline{\tilde{f}}^j(t) \\ \underline{\tilde{r}}^j(t) \\ \underline{\tilde{g}}^j(t) \\ \underline{\tilde{u}}^j(t) \\ \underline{i}^j(t) \end{bmatrix} \qquad (5.12)$$

where the above input-output matrices are those described in Equation 5.11, T again denotes transpose and the vector on the right hand side is that described in Equation 5.9.

Research

Research projects in the College of Engineering are intended to promote or strengthen the educational program. The faculty members in the College of Engineering have primary responsibility for the research project activity and are assisted by undergraduate and graduate students.

In the model, two types of research activities are identified: institutional (organized) research, funded from University souces, and sponsored research, funded from external sources, such as individuals, industrial organizations, and agencies of the government. It is possible to identify three types of sponsored research, i.e. gifts, contracts, or grants; however, this distinction is not made in the proposed model.

Most research effort of personnel in the College of Engineering is conducted through the Office of Engineering Research whose support functions include physical preparation of proposals in collaboration with the faculty; budget calculations; submission of the proposal to potential sponsors; support of the faculty member in preliminary conferences; accounting and billing for awarded contracts, maintenance of central file for all Engineering Research efforts, both sponsored and institutional, etc.

The equations already developed in this chapter have established a pattern that can be adapted to the research function. Therefore, the input-output models and unit costs of production for research as well as extension and public service will be described in terms of the equations already developed.

For institutional research, the input-output model for school j, all projects, is obtained by substituting superscript 3 for superscript 2, the letter h for b, and P_j for M_j in Equation 5.11. The superscripts now denote, respectively, institutional research, school j, and project. P_j individual institutional research projects are identified in school j during the t^{th} time period. The units of measurement for research production presents a problem. Russell (16) observes that it is difficult to define appropriate units for research production. He further indicates that research production seems to be in units that are incommensurable. However, the production unit selected in this dissertation is man-hours of effort because of the direct relationship between personnel expenditures for research and the man-hours of effort of personnel engaged in research activities. Therefore, the typical entry $h^{jl}(t)$ denotes the man-hours of institutional research effort produced in school j on project l during the t^{th} time interval. Selection of a "best" production unit (if indeed, one exists) is beyond the scope of this dissertation, but does indicate an area in which further investigation by others might prove fruitful.

The equation for unit costs of man-hours of institutional research produced in school j on all projects during time period t is obtained by making the same substitutions described for Equation 5.11 in Equation 5.12.

The development for sponsored research is similar to that just described for institutional research. Let Q_j denote the number of sponsored research projects in school j during time period t. Then the equations for sponsored research are obtained by substituting superscript 4 for superscript 3, m for h, Q_j for P_j, and the word "sponsored" for the word "institutional" in the word description above describing how the equations for institutional research are obtained.

Extension and Public Service

Most extension and public service effort of personnel in the College of Engineering is conducted through the Engineering and Industrial Extension Division. Extension programs are specifically designed for individuals who are not able to participate in the regular campus educational activities on a full-time basis.

Extension and public service is broken down into three subfunctions, which are described as:

1. The on-campus non-credit program
2. The off-campus credit course program
3. The off-campus non-credit course program.

The on-campus non-credit program consists of short courses, conferences, seminars, institutes, meetings, workshops, etc. The off-campus credit course program is concerned primarily with a Master's degree program that is a joint endeavor of Oklahoma State University, the University of Tulsa, and the University of Oklahoma. The off-campus non-credit course program denotes contract courses taught to employees of companies or agencies at their request.

Extension and public service activities impose demands upon the resources of the College. The resources allocated to meet these demands and the unit costs of production are described by equations that are similar to those previously described in this chapter for instruction and research. Therefore, a word description will be used to outline the equations for the three sub-functions that constitute extension and public service.

Three equations of the form of Equation 5.11 result from the substitutions described next. The first equation results from making all the substitutions listed first in the series of three, the second equation results from making all the substitutions listed second in the series of three, etc. In Equation 5.11, let the superscripts 5, 6, and 7 (replacing superscript 2) denote, respectively, the on-campus non-credit program, the off-campus credit course program, and the off-campus non-credit course program. Let the superscript j denote school j, and let the third superscript denote activity, course, and course, respectively, for the on-campus non-credit program, the off-campus credit course program, and the off-campus non-credit course program. For b substitute n, w, and y to denote, respectively, the number of man-hours of training produced (on-campus non-credit program), the number of student-credit-hours produced (off-campus credit course program), and the number of man-hours of training produced (off-campus non-credit course program).

Also, for M_j, substitute, respectively, R_j, S_j, and T_j to denote the number of on-campus non-credit activities, off-campus credit courses, and off-campus non-credit courses.

As an example, the entry $n^{j1}(t)$ denotes the number of man-hours of training produced in school j, activity 1 for the on-campus non-credit program during time period t. Note that the man-hours of training produced for the non-credit extension programs is not man-hours of effort produced, as was the case for research. To illustrate, a 4 hour conference with an enrollment of 20 will produce 80 man-hours of training regardless of the man-hours of teaching effort involved.

The equations for unit costs for the three sub-functions of extension and public service are obtained from making those substitutions described above into Equation 5.12.

All Functions

The development in the preceding sections of this chapter describes each function (or sub-function) of the schools separately. Consequently, the input-output characteristics for each function or sub-function can be evaluated and simulated individually. However, a more general case is to consider the input-output characteristics of each school for all functions. It is desirable, at this point, to aggregate the model in order to keep the size of the model within manageable proportions.

To illustrate the changes made in the model, examples of aggregation will be given for instruction. The procedure for research and extension should be evident from these examples.

The first step in aggregation for the on-campus credit course program is to diminish the size of personnel input vectors by placing all individuals into the following categories. Administrators are identified according to P1 types, faculty are identified according to P2 ranks, staff are identified according to P3 types, graduate assistants are identified according to P4 types, and student assistants are identified according to P5 types. The object expenditures vector is not diminished.

For illustration purposes, possible types of school administrators are heads of schools, administrative assistants, and research administrators. Four possible faculty ranks are professor, associate professor, assistant professor, and instructor. Three possible types of school staff are secretaries, technicians, and research personnel. Two possible types of graduate and student assistants are teaching assistants and research assistants. Examples of object expenditures are given in Chapter III.

Using Equation 5.7 as a guide, the personnel input vectors are now diminished. For example, individual faculty member effort is now aggregated according to faculty ranks. The student-credit-hours produced in individual courses is aggregated into student-credit-hours produced by course level. This is achieved by summing the student-credit-hours produced in the N_{jk} courses at course level k, i.e.

$$c^{jk}(t) = \sum_{n=1}^{N_{jk}} c^{jkn}(t) \quad . \qquad (5.13)$$

The FTE's or object expenditures per SCH (student-credit-hour) by level are determined from the input-output matrices of Equation 5.11, and the resulting equation is written as

$$\begin{bmatrix} \underline{a}^{1j}(t) \\ \underline{f}^{1j}(t) \\ \underline{r}^{1j}(t) \\ \underline{g}^{1j}(t) \\ \underline{u}^{1j}(t) \\ \underline{e}^{1j}(t) \end{bmatrix} = \begin{bmatrix} A^{1j1} & \ldots & A^{1j6} \\ F^{1j1} & \ldots & F^{1j6} \\ R^{1j1} & \ldots & R^{1j6} \\ G^{1j1} & \ldots & G^{1j6} \\ P^{1j1} & \ldots & P^{1j6} \\ E^{1j1} & \ldots & E^{1j6} \end{bmatrix} \begin{bmatrix} c^{j1}(t) \\ \cdot \\ \cdot \\ \cdot \\ c^{j6}(t) \end{bmatrix} = \begin{bmatrix} A^{1j} \\ F^{1j} \\ R^{1j} \\ G^{1j} \\ P^{1j} \\ E^{1j} \end{bmatrix} [\underline{c}^{j}(t)] \qquad (5.14)$$

Since personnel have been aggregated, the unit costs of personnel must be aggregated and now represent <u>average</u> unit costs. A "hat" will be used on these vectors to indicate this change. It follows from Equation 5.14 that SCH costs by course level may be represented as:

$$\hat{\underline{c}}^{j}(t) = \begin{bmatrix} A^{1j} \\ F^{1j} \\ R^{1j} \\ G^{1j} \\ P^{1j} \\ E^{1j} \end{bmatrix}^{T} \begin{bmatrix} \hat{\underline{a}}^{1j}(t) \\ \hat{\underline{f}}^{1j}(t) \\ \hat{\underline{r}}^{1j}(t) \\ \hat{\underline{g}}^{1j}(t) \\ \hat{\underline{u}}^{1j}(t) \\ \underline{i}^{j}\ (t) \end{bmatrix} \qquad (5.15)$$

Aggregation of personnel and unit costs of personnel are the only steps required for activities related to the on-campus instructional program. This procedure is identical to that just described for the on-campus credit course program. The input-output model for school j is then written as:

$$\begin{bmatrix} \underline{a}^{2j}(t) \\ \underline{f}^{2j}(t) \\ \underline{r}^{2j}(t) \\ \underline{g}^{2j}(t) \\ \underline{u}^{2j}(t) \\ \underline{e}^{2j}(t) \end{bmatrix} = \begin{bmatrix} A^{2j1} & \ldots & A^{2jM_j} \\ F^{2j1} & \ldots & F^{2jM_j} \\ R^{2j1} & \ldots & R^{2jM_j} \\ G^{2j1} & \ldots & G^{2jM_j} \\ P^{2j1} & \ldots & P^{2jM_j} \\ E^{2j1} & \ldots & E^{2jM_j} \end{bmatrix} \begin{bmatrix} b^{j1}(t) \\ \cdot \\ \cdot \\ \cdot \\ b^{jM_j}(t) \end{bmatrix} = \begin{bmatrix} A^{2j} \\ F^{2j} \\ R^{2j} \\ G^{2j} \\ P^{2j} \\ E^{2j} \end{bmatrix} [\underline{b}^{j}(t)] \quad (5.16)$$

From Equation 5.16, it follows that the unit costs of producing man-hours of effort for activities related to the on-campus instruction program are:

$$\underline{\hat{b}}^{j}(t) = - \begin{bmatrix} A^{2j} \\ F^{2j} \\ R^{2j} \\ G^{2j} \\ P^{2j} \\ E^{2j} \end{bmatrix}^{T} \begin{bmatrix} \underline{\hat{a}}^{2j}(t) \\ \underline{\hat{f}}^{2j}(t) \\ \underline{\hat{r}}^{2j}(t) \\ \underline{\hat{g}}^{2j}(t) \\ \underline{\hat{u}}^{2j}(t) \\ \underline{i}^{j}(t) \end{bmatrix} \quad (5.17)$$

The input-output models and unit cost equations for the remaining five sub-functions are developed in a fashion similar to that just described. Thus, the input-output model of school j for all functions can be represented as:

$$\begin{bmatrix} \underline{a}^j(t) \\ \underline{f}^j(t) \\ \underline{r}^j(t) \\ \underline{g}^j(t) \\ \underline{u}^j(t) \\ \underline{e}^j(t) \end{bmatrix} = \begin{bmatrix} A^{1j} & A^{2j} & A^{3j} & A^{4j} & A^{5j} & A^{6j} & A^{7j} \\ F^{1j} & F^{2j} & F^{3j} & F^{4j} & F^{5j} & F^{6j} & F^{7j} \\ R^{1j} & R^{2j} & R^{3j} & R^{4j} & R^{5j} & R^{6j} & R^{7j} \\ G^{1j} & G^{2j} & G^{3j} & G^{4j} & G^{5j} & G^{6j} & G^{7j} \\ P^{1j} & P^{2j} & P^{3j} & P^{4j} & P^{5j} & P^{6j} & P^{7j} \\ E^{1j} & E^{2j} & E^{3j} & E^{4j} & E^{5j} & E^{6j} & E^{7j} \end{bmatrix} \begin{bmatrix} \underline{c}^j(t) \\ \underline{b}^j(t) \\ \underline{h}^j(t) \\ \underline{m}^j(t) \\ \underline{n}^j(t) \\ \underline{w}^j(t) \\ \underline{y}^j(t) \end{bmatrix} \quad (5.18)$$

Also, in terms of the resources utilized and resource costs, the unit costs of production for all functions in school j during time period t are:

$$\begin{bmatrix} \hat{\underline{c}}^j(t) \\ \hat{\underline{b}}^j(t) \\ \hat{\underline{h}}^j(t) \\ \hat{\underline{m}}^j(t) \\ \hat{\underline{n}}^j(t) \\ \hat{\underline{w}}^j(t) \\ \hat{\underline{y}}^j(t) \end{bmatrix} = - \begin{bmatrix} A^{1j} & A^{2j} & A^{3j} & A^{4j} & A^{5j} & A^{6j} & A^{7j} \\ F^{1j} & F^{2j} & F^{3j} & F^{4j} & F^{5j} & F^{6j} & F^{7j} \\ R^{1j} & R^{2j} & R^{3j} & R^{4j} & R^{5j} & R^{6j} & R^{7j} \\ G^{1j} & G^{2j} & G^{3j} & G^{4j} & G^{5j} & G^{6j} & G^{7j} \\ P^{1j} & P^{2j} & P^{3j} & P^{4j} & P^{5j} & P^{6j} & P^{7j} \\ E^{1j} & E^{2j} & E^{3j} & E^{4j} & E^{5j} & E^{6j} & E^{7j} \end{bmatrix}^T \begin{bmatrix} \hat{\underline{a}}^j(t) \\ \hat{\underline{f}}^j(t) \\ \hat{\underline{r}}^j(t) \\ \hat{\underline{g}}^j(t) \\ \hat{\underline{u}}^j(t) \\ \underline{i}^j(t) \end{bmatrix} \quad (5.19)$$

In Equations 5.18 and 5.19, the superscript j denotes school j and the superscripts, 1, 2, 3, 4, 5, 6 and 7 denote, respectively, the on-campus credit course program, activities related to the on-campus instructional program, institutional research, sponsored research, the on-campus non-credit program, the off-campus credit course program, and the off-campus non-credit course program.

The left-hand-side of Equation 5.18 can be determined directly from the data base. It is also possible to determine these vectors from:

$$\begin{bmatrix} \underline{a}^j(t) \\ \underline{f}^j(t) \\ \underline{r}^j(t) \\ \underline{g}^j(t) \\ \underline{u}^j(t) \\ \underline{e}^j(t) \end{bmatrix} = \sum_{k=1}^{7} \begin{bmatrix} \underline{a}^{kj}(t) \\ \underline{f}^{kj}(t) \\ \underline{r}^{kj}(t) \\ \underline{g}^{kj}(t) \\ \underline{u}^{kj}(t) \\ \underline{e}^{kj}(t) \end{bmatrix} \tag{5.20}$$

where the right-hand-side of Equation 5.20 denotes a summation of corresponding vectors. Superscripts k and j denote, respectively, subfunction k and school j.

In Equation 5.19, $\hat{\underline{a}}^j(t)$, $\hat{\underline{f}}^j(t)$, $\hat{\underline{r}}^j(t)$, $\hat{\underline{g}}^j(t)$, and $\hat{\underline{u}}^j(t)$ are the average unit costs, respectively, of $\underline{a}^j(t)$, $\underline{f}^j(t)$, $\underline{r}^j(t)$, $\underline{g}^j(t)$, and $\underline{u}^j(t)$. These average costs can be determined directly from the data base.

At this point it is desirable to show how the total budget for personnel and object expenditures of each school can be determined. The inner product

$$\begin{bmatrix} \underline{c}^j(t) \\ \underline{b}^j(t) \\ \underline{h}^j(t) \\ \underline{m}^j(t) \\ \underline{n}^j(t) \\ \underline{w}^j(t) \\ \underline{y}^j(t) \end{bmatrix}^T \begin{bmatrix} \hat{\underline{c}}^j(t) \\ \hat{\underline{b}}^j(t) \\ \hat{\underline{h}}^j(t) \\ \hat{\underline{m}}^j(t) \\ \hat{\underline{n}}^j(t) \\ \hat{\underline{w}}^j(t) \\ \hat{\underline{y}}^j(t) \end{bmatrix}$$

establishes the total cost for all sub-functions and thus the total budget of school j for the t^{th} time period. Another way to determine the total budget is from the inner product

$$\begin{bmatrix} \underline{a}^j(t) \\ \underline{f}^j(t) \\ \underline{r}^j(t) \\ \underline{g}^j(t) \\ \underline{u}^j(t) \\ \underline{e}^j(t) \end{bmatrix}^T \begin{bmatrix} \hat{\underline{a}}^j(t) \\ \hat{\underline{f}}^j(t) \\ \hat{\underline{r}}^j(t) \\ \hat{\underline{g}}^j(t) \\ \hat{\underline{u}}^j(t) \\ \underline{i}^j(t) \end{bmatrix} .$$

The input-output model of the College follows from the input-output models of the schools in the College. The input-output model of the College, considering all schools and all functions, is represented as:

$$\begin{bmatrix} \underline{a}(t) \\ \underline{f}(t) \\ \underline{r}(t) \\ \underline{g}(t) \\ \underline{u}(t) \\ \underline{e}(t) \end{bmatrix} = \begin{bmatrix} A^1 & A^2 & A^3 & A^4 & A^5 & A^6 & A^7 \\ F^1 & F^2 & F^3 & F^4 & F^5 & F^6 & F^7 \\ R^1 & R^2 & R^3 & R^4 & R^5 & R^6 & R^7 \\ G^1 & G^2 & G^3 & G^4 & G^5 & G^6 & G^7 \\ P^1 & P^2 & P^3 & P^4 & P^5 & P^6 & P^7 \\ E^1 & E^2 & E^3 & E^4 & E^5 & E^6 & E^7 \end{bmatrix} \begin{bmatrix} \underline{c}(t) \\ \underline{b}(t) \\ \underline{h}(t) \\ \underline{m}(t) \\ \underline{n}(t) \\ \underline{w}(t) \\ \underline{y}(t) \end{bmatrix} . \quad (5.21)$$

Also, in terms of the resources utilized and resource costs, the unit costs of production for all functions in the College during time period t are:

$$\begin{bmatrix} \underline{\hat{c}}(t) \\ \underline{\hat{b}}(t) \\ \underline{\hat{h}}(t) \\ \underline{\hat{m}}(t) \\ \underline{\hat{n}}(t) \\ \underline{\hat{w}}(t) \\ \underline{\hat{y}}(t) \end{bmatrix} = - \begin{bmatrix} A^1 & A^2 & A^3 & A^4 & A^5 & A^6 & A^7 \\ F^1 & F^2 & F^3 & F^4 & F^5 & F^6 & F^7 \\ R^1 & R^2 & R^3 & R^4 & R^5 & R^6 & R^7 \\ G^1 & G^2 & G^3 & G^4 & G^5 & G^6 & G^7 \\ P^1 & P^2 & P^3 & P^4 & P^5 & P^6 & P^7 \\ E^1 & E^2 & E^3 & E^4 & E^5 & E^6 & E^7 \end{bmatrix}^T \begin{bmatrix} \underline{\hat{a}}(t) \\ \underline{\hat{f}}(t) \\ \underline{\hat{r}}(t) \\ \underline{\hat{g}}(t) \\ \underline{\hat{u}}(t) \\ \underline{i}(t) \end{bmatrix} \qquad (5.22)$$

In Equations 5.21 and 5.22, the superscripts, 1, 2, 3, 4, 5, 6, and 7 denote, respectively, the sub-functions described in Equations 5.19 and 5.20. The vector $\underline{a}(t)$ is defined as:

$$\underline{a}(t) = \begin{bmatrix} \underline{a}^1(t) \\ \underline{a}^2(t) \\ \cdot \\ \cdot \\ \cdot \\ \underline{a}^{M1}(t) \end{bmatrix} \qquad (5.23)$$

i.e. $\underline{a}(t)$ is comprised of the vectors $\underline{a}^j(t)$ for the M1 schools of the College. The other vectors appearing on the right and left-hand-sides of Equations 5.21 and 5.22 are similarly defined.

CHAPTER VI

THE COLLEGE SYSTEM MODEL

Introduction

The model of the student sector developed in Chapter IV and the model of the production sector developed in Chapter V are unconstrained models. That is, the input-output characteristics of each sector model may be simulated independently by providing the appropriate input data. However, simultaneous operation of both sectors as an integral unit implies that constraints must be imposed. These constraints are easily identified in terms of the common variables appearing in the models of the student and production sectors.

It is clear that the graduate and student assistantships, denoted by $\underline{g}(t)$ and $\underline{u}(t)$, respectively, in the student sector model Equation 4.13, are identical to those quantities utilized in the production sector model Equation 5.21. Furthermore, the student-credit-hours demanded, denoted by $\underline{c}(t)$ in Equation 4.20, correspond to the student-credit-hours produced in Equation 5.21. Finally, the unit costs of the student-credit-hours demanded, denoted by $\hat{\underline{c}}(t)$ in Equation 4.39, are considered to be the negative of the unit values of the student-credit-hours produced in the production sector model Equation 5.22. This constraint is consistent with the convention that unit costs of inputs are positive while unit costs of outputs are negative.

Combining the Sector Models

The College system model is established by replacing the constraint variables in the sector models with equivalent relationships.

The equation describing the student enrollment distribution of the College is obtained by making the following substitutions into Equation 4.13, which is repeated here for convenience:

$$\underline{s}(t) = T(t)\underline{s}(t-1) + Q(t)\underline{p}(t-1) + X(t)\underline{q}(t-1) + H\underline{g}(t) + J\underline{u}(t) \quad (6.1)$$

First $\underline{g}(t)$ and $\underline{u}(t)$ are replaced by their equivalents from Equation 5.21. Then applying Equation 4.20 to the result and solving for $\underline{s}(t)$ yields:

$$\underline{s}(t) = B^{-1}T(t)\underline{s}(t-1) + B^{-1}Q(t)\underline{p}(t-1) + B^{-1}X(t)\underline{q}(t-1) + B^{-1}B^{1}\underline{x}(t)$$
$$+ B^{-1}B^{2}\underline{b}(t) + B^{-1}B^{3}\underline{h}(t) + B^{-1}B^{4}\underline{m}(t) + B^{-1}B^{5}\underline{n}(t) + B^{-1}B^{6}\underline{w}(t)$$
$$+ B^{-1}B^{7}\underline{y}(t) \quad (6.2)$$

where

$$B^{-1} = (I - HG^{1}C - JP^{1}C)^{-1} \quad (6.3a)$$
$$B^{1} = (HG^{1}\Phi + JP^{1}\Phi) \quad (6.3b)$$
$$B^{2} = (HG^{2} + JP^{2}) \quad (6.3c)$$
$$B^{3} = (HG^{3} + JP^{3}) \quad (6.3d)$$
$$B^{4} = (HG^{4} + JP^{4}) \quad (6.3e)$$
$$B^{5} = (HG^{5} + JP^{5}) \quad (6.3f)$$
$$B^{6} = (HG^{6} + JP^{6}) \quad (6.3g)$$
$$B^{7} = (HG^{7} + JP^{7}) \quad . \quad (6.3h)$$

Note that I denotes the identity matrix in Equation 6.3a and B^{-1} denotes matrix inverse. The superscripts 1 through 7 appearing on certain matrices in Equations 6.2 and 6.3a-6.3h denote sub-functions (not powers).

For a fixed set of operating policies, any increase in demands for services provided by the College results in an increased demand for student and graduate assistant effort. An increase in the number of student and graduate assistants raises student enrollment and creates an additional demand for credit hours of instruction. This interdependence is described explicitly in Equation 6.2.

The equation describing the average imputed values of students in the College is obtained by making the following substitutions into Equation 4.39, which is repeated here for convenience:

$$\underline{\hat{s}}(t) = Y^{u}(t)\underline{\hat{s}}(t-1) - Y^{v}(t)\underline{\hat{p}}(t-1) - Y^{w}(t)\underline{\hat{q}}(t-1) - C^{T}\underline{\hat{c}}(t) - M^{T}\underline{\hat{o}}(t) \quad . \quad (6.4)$$

First $\underline{\hat{c}}(t)$ is replaced by $-\underline{\hat{c}}(t)$, accounting for the change in sign from input to output cost. Then the expression for $\underline{\hat{c}}(t)$ obtained from Equation 5.22 is utilized, giving:

$$\begin{aligned} \underline{\hat{s}}(t) = {} & Y^{u}(t)\underline{\hat{s}}(t-1) - Y^{v}(t)\underline{\hat{p}}(t-1) - Y^{w}(t)\underline{\hat{q}}(t-1) \\ & -C^{T}[A^{1T}F^{1T}R^{1T}G^{1T}P^{1T}E^{1T}] \begin{bmatrix} \underline{\hat{a}}(t) \\ \underline{\hat{f}}(t) \\ \underline{\hat{r}}(t) \\ \underline{\hat{g}}(t) \\ \underline{\hat{u}}(t) \\ \underline{i}(t) \end{bmatrix} - M^{T}\underline{\hat{o}}(t) \end{aligned} \quad (6.5)$$

An examination of Equation 6.5 shows the dependency of the imputed student values upon the cost of the personnel resources and object expenditures allocated in the production sector for credit hours of instruction.

Administration, faculty, and staff effort plus object expenditures for all production in the College, obtained from Equation 5.21 is:

$$\begin{bmatrix} \underline{a}(t) \\ \underline{f}(t) \\ \underline{r}(t) \\ \underline{e}(t) \end{bmatrix} = \begin{bmatrix} A^1 & A^2 & A^3 & A^4 & A^5 & A^6 & A^7 \\ F^1 & F^2 & F^3 & F^4 & F^5 & F^6 & F^7 \\ R^1 & R^2 & R^3 & R^4 & R^5 & R^6 & R^7 \\ E^1 & E^2 & E^3 & E^4 & E^5 & E^6 & E^7 \end{bmatrix} \begin{bmatrix} \underline{c}(t) \\ \underline{b}(t) \\ \underline{h}(t) \\ \underline{m}(t) \\ \underline{n}(t) \\ \underline{w}(t) \\ \underline{y}(t) \end{bmatrix} \quad (6.6)$$

Using Equation 4.20 in Equation 6.6 yields:

$$\begin{bmatrix} \underline{a}(t) \\ \underline{f}(t) \\ \underline{r}(t) \\ \underline{e}(t) \end{bmatrix} = \begin{bmatrix} A^1C \\ F^1C \\ R^1C \\ E^1C \end{bmatrix} \underline{s}(t) + \begin{bmatrix} A^1\bar{\Phi} \\ F^1\bar{\Phi} \\ R^1\bar{\Phi} \\ E^1\bar{\Phi} \end{bmatrix} \underline{x}(t) + \begin{bmatrix} A^2 & A^3 & A^4 & A^5 & A^6 & A^7 \\ F^2 & F^3 & F^4 & F^5 & F^6 & F^7 \\ R^2 & R^3 & R^4 & R^5 & R^6 & R^7 \\ E^2 & E^3 & E^4 & E^5 & E^6 & E^7 \end{bmatrix} \begin{bmatrix} \underline{b}(t) \\ \underline{h}(t) \\ \underline{m}(t) \\ \underline{n}(t) \\ \underline{w}(t) \\ \underline{y}(t) \end{bmatrix} \quad (6.7)$$

Equation 6.7 shows explicitly that for a fixed set of operating policies, any increase of either the number of College students, $\underline{s}(t)$, or the number of non-engineering students, $\underline{x}(t)$, results in an increased demand for administrative, faculty, and staff effort as well as object expenditures.

From Equation 5.22, the equation for unit costs of production for activities related to the on-campus instruction program, institutional research, sponsored research, the on-campus non-credit program, the off-campus credit course program, and the off-campus non-credit course program is:

$$\begin{bmatrix} \hat{\underline{b}}(t) \\ \hat{\underline{h}}(t) \\ \hat{\underline{m}}(t) \\ \hat{\underline{n}}(t) \\ \hat{\underline{w}}(t) \\ \hat{\underline{y}}(t) \end{bmatrix} = - \begin{bmatrix} A^2 & A^3 & A^4 & A^5 & A^6 & A^7 \\ F^2 & F^3 & F^4 & F^5 & F^6 & F^7 \\ R^2 & R^3 & R^4 & R^5 & R^6 & R^7 \\ G^2 & G^3 & G^4 & G^5 & G^6 & G^7 \\ P^2 & P^3 & P^4 & P^5 & P^6 & P^7 \\ E^2 & E^3 & E^4 & E^5 & E^6 & E^7 \end{bmatrix}^T \begin{bmatrix} \hat{\underline{a}}(t) \\ \hat{\underline{f}}(t) \\ \hat{\underline{r}}(t) \\ \hat{\underline{g}}(t) \\ \hat{\underline{u}}(t) \\ \underline{i}(t) \end{bmatrix} . \tag{6.8}$$

Equation 6.8 describes the unit costs of production for all services provided except the on-campus credit course program. At present, none of the unit costs described in Equation 6.8 are included in the equation for average imputed values of students given by Equation 6.5. However, those components of $\hat{\underline{b}}(t)$ that denote unit costs for student advisement could be included in Equation 6.5 if desired.

The Inverse Matrix

In Equation 6.2, the inverse of the matrix B, defined by Equation 6.3a, is required in solving for $\underline{s}(t)$. If the matrix B is singular, B^{-1} does not exist and one cannot express $\underline{s}(t)$ as shown in Equation 6.2. However, it will be shown that if certain conditions are satisfied, then the inverse will always exist.

Let

$$A = [HG^1C + JP^1C] = [a_{ij}]_{NxN} \quad . \qquad (6.9)$$

The entry a_{ij} represents the ratio obtained by dividing the number of College students enrolled in category i that are utilized as graduate and/or student assistants in producing credit hours of instruction for College students enrolled in category j by the total number of students enrolled in category j. Therefore, if it is assumed that in each student category, the number of graduate and/or student assistants utilized in producing credit hours of instruction for all student categories is less than the smallest student enrollment in any category and if it is also assumed that the number of graduate and/or student assistants utilized in each student category is less than the student enrollment in any category, then the entries a_{ij} satisfy the following two conditions, respectively:

$$0 \leq \sum_{j=1}^{N} a_{ij} < 1 , \qquad i=1,\ldots,N \qquad (6.10)$$

and

$$0 \leq a_{ij} < 1 , \qquad i=1,\ldots,N; \; j=1,\ldots,N \quad . \qquad (6.11)$$

<u>Theorem 6.1</u>. Given the matrix $A = [a_{ij}]_{NxN}$ satisfying conditions 6.10 and 6.11, each eigenvalue of A is modulus less than 1.

<u>Proof</u>. Let λ be an eigenvalue of A and let $\underline{x} = [X_1,\ldots,X_m,\ldots,X_N]^T$ be a corresponding eigenvector with $|X_m|$ the magnitude of the largest entry. Clearly $|X_m| \neq 0$. Then, since $\lambda\underline{x} = A\underline{x}$,

$$\lambda X_m = \sum_{j=1}^{N} a_{mj} X_j \quad . \qquad (6.12)$$

Taking the absolute value of both sides of Equation 6.12 gives

$$\left|\lambda X_m\right| = \left|\sum_{j=1}^{N} a_{mj}X_j\right| \quad .$$

Using the triangle inequality,

$$\left|\lambda X_m\right| \le \sum_{j=1}^{N} \left|a_{mj}X_j\right|$$

which is equivalent to

$$\left|\lambda\right|\left|X_m\right| \le \sum_{j=1}^{N} \left|a_{mj}X_j\right| \quad .$$

Therefore,

$$\left|\lambda\right| \le \sum_{j=1}^{N} \left|a_{mj}\right| \frac{\left|X_j\right|}{\left|X_m\right|} \quad .$$

But since $\left|X_j\right| \le \left|X_m\right|$, $j=1,\ldots,N$,

$$\left|\lambda\right| \le \sum_{j=1}^{N} \left|a_{mj}\right|$$

so that $\left|\lambda\right| < 1$ in view of conditions 6.10 and 6.11.

The following two theorems, stated without proof (17,18) establish the existence of $B^{-1} = (I - A)^{-1}$ and the non-negativity of its entries.

Theorem 6.2. $A^n \to 0$ as $n \to \infty$ if and only if each eigenvalue of A is of modulus less than 1.

In Theorem 6.2, A^n denotes the n^{th} power of A.

Theorem 6.3. In order that the series

$$I + A + A^2 + \ldots + A^n + \ldots$$

converge, it is necessary and sufficient that $A^n \rightarrow 0$ as $n \rightarrow \infty$. In such a case the sum of the series equals $(I - A)^{-1}$.

Combining the results of Theorems 6.1, 6.2, and 6.3, it is first of all clear that B^{-1} defined by Equation 6.3a will always exist if conditions 6.10 and 6.11 are satisfied. Furthermore, it can be seen from Equation 6.2 that for $\underline{s}(t)$ to exhibit positive entries, all entries of B^{-1} must be positive.

CHAPTER VII

DATA BASE REQUIREMENTS

Introduction

The model of the College formulated in Chapters IV, V, and VI requires specific types of data for implementation. However, a data base in the form suitable for total implementation of the model does not exist at present. The accuracy of any model depends upon an accurate and adequate data base from which the parameters in the model can be evaluated. It is hoped that in the near future, an adequate data base will be developed. In the meantime, simulation efforts must be based upon skeleton information and hypothetical data in order to demonstrate the model.

Insofar as this model is concerned, the data base should be centralized, coordinated, and computerized. This should eliminate duplication of data collection and provide detailed information concerning the operation of the College with provisions to insure against use by unauthorized persons. Data acquisitions should be synchronized in time, data should be updated periodically, and a standard code should be used.

One specific objective of this study was to establish and define the data base requirements for a system model of the College. The very first step in this investigation was to confer with school, College, and University officials and administrators in order to determine the present data base and to ascertain their future plans in this area. After information on the present data base and future data base plans were obtained, the model described in this dissertation was formulated. Thus, the model describing the College was influenced by and is compatible with the data base available.

The University has in existence now a reasonably complete data base on students as well as faculty and staff. The file on faculty and staff contains information taken from the "Request for Personnel Action" form. This file also contains information taken from application forms filled out by faculty and staff members.

The student file contains information taken from class card records and other records completed by students in the registration process. Additional steps are being taken to make both files more complete. With respect to these files, data for the current semester are stored on discs and then placed on magnetic tape when they are no longer current.

The University receives a large number of requests for information concerning various aspects of University operation from other colleges and universities, government agencies, boards of regents, legislative committees, boards of accreditation, etc. An adequate computerized data base should be able to meet these requests with the proper data supplied quickly, conveniently, and accurately.

At the present time, a survey is being made concerning the nature of records to be kept in a computer-based information system. It is anticipated that data will be stored on disc files allowing random access call-out. Also, inactive files will be pulled off disc storage and stored on magnetic tape.

Since one objective of this research is to define the data base required to implement the mathematical model of the College of Engineering, it is hoped that the requirements specified for the College will aid or influence University administrators in their determination of records that should be kept for the University.

Specific Data Needed

A logical progression in developing the data base for the model is to first consider the specific data requirements for each of the individual sectors. The information needed for the student sector is referred to as the "Student Master Record". For evaluation of Equation 4.13, it is essential that the following data be provided:

1. The school and student level of each student enrolled in the College during a given semester. The categories of "Engineering Freshman" and "Engineering Sophomore" are used to describe College students who have not yet declared their majors. Also, the category "Engineering Special" describes those students who are not candidates for a degree.
2. The enrollment status of each student for the previous semester. Arrivals from off-campus are categorized as new high school graduates, transfers from another college or university, and readmission students. Transfers from on-campus are classified according to origins of transfers. In addition, it is necessary to identify those students continuing in the College from the previous semester.
3. Identification of those students awarded graduate and student assistantships and the full-time-equivalent of each assistantship.

Some of the information required for evaluation of Equation 4.13 is available from the "Registration Permit". This permit contains information concerning the student's college, classification (Freshman, Sophomore, Junior, Senior, Masters, Doctors, and Special), and major. Since some schools of the College offer more than one major, the majors offered in each school would have to be identified to determine the school and student level of each student in the College from this record. The registration permit also contains coded information that tells whether an individual is a recent high school graduate, transfer student, readmission student, or a continuing student.

Another source of information that could be used to partially implement Equation 4.13 is the "College of Engineering Information Sheet". In fact, with several additional questions added to this sheet, it would be relatively easy to collect the necessary data from this form. Simply query the students concerning their student levels (identifying "Special" students), the enrollment status of each student for the previous semester, and identify those students awarded graduate and student assistantships and the full-time equivalent of each assistantship.

If the "Student Master Record" is to be updated during the semester, the "College Transfer Permit" and "Curriculum (or Department) Transfer Permit" could be used to determine, respectively, the number of students transferring into and out of the College and the number of students changing school within the College. Students changing from undergraduate to graduate status should also list the name of the college into which they are transferring. Describing a student as being enrolled in the Graduate College is not descriptive enough.

In order to implement Equation 4.17, the reason(s) for a student's departure must be known. If a student graduates, this information should be indicated in the "Student Master Record". At the present time, about the only means of determining if a student has graduated is to look at official records after graduation ceremonies have been conducted. If a student departs the College and re-enrolls in another college in the University, this information could be determined from the College Transfer Permit. Also, if a student officially withdraws from the College, this information is available from the Registrar. However, no list is maintained for unofficial withdrawals.

The data required to implement Equations 4.20 and 4.25 could be obtained from several sources. Student enrollment data for the College and for non-engineering students could be obtained from registration permits. The credit hours taken by students enrolled in various colleges of the University could be obtained from class cards. The Office of Institutional Research will have class card data on magnetic tape for eleven previous semesters at the end of the Spring semester, 1969. Thus, credit hours taken during previous semesters could also be calculated.

The data requirements for Equation 4.39 have already been described in Chapter IV. The unit costs of student-credit-hours demanded from the college, $\underline{\hat{c}}(t)$, is determined in the production sector. However, unit costs of student-credit-hours demanded from non-engineering academic units, $\underline{\hat{o}}(t)$, will have to be supplied by non-engineering academic units

The data base required to implement the production sector will now be described. The equations describing the characteristics of the production sector have a similar form for the seven sub-functions defined in Chapter V. Thus, it should be clear that the data needed to evaluate the equations describing one sub-function will be very similar in form to the data needed to evaluate all sub-functions.

Equation 5.7 requires that individual administrative, faculty, staff, graduate assistant, and student assistant effort as well as object expenditures be determined for each course offered by a given school in the College for each semester. Faculty, graduate assistant, and student assistant effort can be determined from records kept by the individual schools. Certain object expenditures might also be determined. For example, the University Computer Center maintains rather extensive records on use of the 360 Mod 50 computer and charges could be made to individual courses. An estimate of costs attributed to individual courses could be made for the 1620 computer located in Engineering South. Class cards contain information on the time and place of each class meeting. Thus a use charge could be made for room usage.

If an administrator or staff member teaches a particular course, he could estimate his effort. However, administrative and staff effort and object expenditures are primarily indirect efforts or expenses that must be distributed to individual courses on some equitable basis if school expenses for each course are to be determined.

Records are not kept on object expenditures for each course. In fact, certain object expenditures for instruction and institutional research are lumped together at present.

The cost of developing and maintaining a data base should be kept in mind. There is a trade-off between the detail of data provided and the cost of the data base.

The student-credit-hours produced in Equation 5.7 can be determined from class cards. If the departmental course number does not end in zero, then the number of students enrolled times the credit hours associated with the course gives the number of student-credit-hours produced. However, if the departmental course number ends in zero, the student indicates the number of credit-hours he expects to receive for the course. The number of student-credit-hours produced is then determined by summing the number of credit-hours for each student enrollment in the course.

The input-output matrices in Equation 5.7 are computed once the inputs and outputs are determined.

The unit costs of student-credit-hours produced in each course are determined from Equation 5.9. Here unit cost information (dollars per FTE) for administrators, faculty, staff, graduate assistants, and student assistants is required. Unit costs of personnel could be determined from school records or personnel action forms.

Personnel action forms and similar official records do not always give an adequate picture of the specific activities of each employee for a particular semester. Hence, some type of service report is desirable. It is essential that all service report data for a given school or other administrative unit be reviewed by the school head or similar responsible person who is in a position to make consistent evaluations of distribution of effort, i.e. FTE's among activities reported. It is also essential that the service report indicate all activities which contribute to the recognized function of the College.

The University requires that each faculty member complete a Faculty Service Report. In addition, the College of Engineering utilizes two service reports. One is an abbreviated form for Non-Academic service and the other is a rather complete service report. With several modifications, the College of Engineering Service Report could serve as a means for determining most of the data required to implement the production sector of the model. For example, on the service report miscellaneous activities related to instruction such as student advisement, course outlines, and correspondence should have the FTE effort reported for each of these activities. Extension activities must describe the FTE effort for on-campus non-credit activities, off-campus credit courses, and off-campus non-credit courses. Each activity or course must have the activity described by name and number. Additionally, the number of man-hours and student-credit-hours produced should be given, respectively, for these activities and courses.

A service report offers several advantages over other official records in that it allows a detailed indication of the specific activities that each employee engages in and it answers several important questions that are not answered elsewhere. For example, suppose that a faculty member is employed 1/2 time in teaching. Suppose also that he teaches one undergraduate and one graduate course. What then is his division of time between the two courses that he teaches? Is it simply 1/4 time to each course? The point to be made is that the time spent on one course may be much more than that spent on the other due to course difficulty, student enrollment, etc. An improved service report allowing a more detailed breakdown of faculty and staff effort would allow a more accurate allocation to be carried into the simulation.

Allocating Indirect Costs

This section is intended to provide a brief description of allocating indirect costs with respect to the model described in this dissertation. It is hoped that this introduction might interest other investigators in order that work be done in this area.

The problem is to allocate indirect (overhead) costs, such as salaries and wages of school and College administrators and staff, to the various functions performed by the schools in the College. Harris (19) notes the problems involved in cost analysis. He quotes a study of the cost of medical education at Emory University in which the following conclusion appeared.

> Cost analysis, no matter what system is used is not an exact science but, rather like medicine, an art based upon a science. It is an art in the same sense that judgment is an important part of the process. Judgment must be used in such matters as determining how to distribute each overhead cost most equitably and develop the best estimate for the distribution of personnel time, determining where the exceptions to the established rules are justified, or perhaps in considering the relationship of the purpose of an expenditure to the method of distribution. Obviously, these judgments must be based upon a familiarity with the general philosophy of the enterprise under study. These judgments should be supported by reason, and reason of course, is frequently debatable.

Morrell (20) notes that by not including capital depreciation as an operating expense, colleges understate educational costs. It is his opinion that assets should be recorded at their replacement value. (By State law, universities cannot depreciate capital investments. These investments must be reported at book value.) Morrell also underscores the central theme of this dissertation in the following statement.

> Profit, which can serve commercial enterprises as a yardstick to measure management effectiveness, does not exist for a college. At present there is no recognized objective means of measuring management effectiveness of a college. The major function of the college accounting system is thus one of stewardship.
>
> With financial reporting of colleges becoming more detailed and data being made more readily available to the public, the emphasis of the accounting system is shifting from stewardship to the providing of financial data revealing realistic costs of operation.
>
> A primary reason for the shift is the financial burden colleges now have. With colleges now facing deficits, the accounting system must supply cost information pertaining to all activities. The system provides college administration with data useful in reaching resource allocation decisions.

In 1932, the National Committee on Standards Reports published a bulletin describing methods used in unit cost studies in higher education (21). A section of this study was devoted to the allocation of salaries and overhead expenditures to courses, curriculums, departments, colleges, etc. Some of the studies cited in this bulletin allocated overhead expenditures to departments by various methods such as the physical space used by the various departments, the number of student-credit-hours produced, instructional salaries, total departmental expenditures, the number of student-clock-hours produced, etc.

A study in 1953 revealed that college and universities still used a wide variety of methods to allocate indirect expenditures (22). The term "indirect expenditures" in this 1953 study includes expenditures for instruction as well as for the three categories generally thought of as indirect expenditures, namely administration and general expenditures, libraries, and the operation and maintenance of the physical plant.

The point to be made is that a variety of bases exist for allocating indirect expenditures. It may well be that the different methods are defensible in the institutions where they were used. However, research in this area is needed to answer such questions as: What statistical evidence is there that allocating general administrative expenditures on a dollar-volume basis is more desirable than on a FTE student basis? Does a method that combines two or more methods assure greater accuracy and validity than the use of one method?

With respect to the model formulated in this dissertation, it is proposed that every individual in each school of the College complete a detailed service report at the end of each semester. The service report should list the three main functions (instruction, research, and extension) broken down into sub-functions. As mentioned previously in this chapter, it is essential that all service report data be reviewed by school heads or similar responsible persons.

When records are not kept to distinguish non-personnel expenditures according to sub-functions, it is suggested that administrators use their best judgment in allocating these costs.

At the College level, it is proposed that expenses of the Dean's Office be allocated to the schools and the functions performed by the schools according to the best judgment of responsible persons in the Dean's Office.

Typical questions that need to be answered are: What method or methods of distributing indirect costs to courses, course levels, projects, activities, etc. are most equitable? If one distributed indirect costs to courses based on student-credit-hours produced for example, then should certain level courses be more heavily weighted than others?

Clearly, additional study of methods to allocate indirect costs is required. However, should future investigators extend this prototype model to include the entire University, then it follows that allocating indirect costs will be explicitly achieved in the model.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

Summary

The research reported in this dissertation was directed toward the development of a detailed resource allocation model for use by University administrators as an aid to operational analysis and decision-making. The model is intended to be a prototype characterization which describes the allocation of resources in the form of personnel and object expenditures to the three main functions of the University - namely, instruction, research, and extension.

Although the model has been developed using the College of Engineering and its schools as an example, the basic structure of the model has been conceived so as to allow direct application to any college within the University.

The research effort was primarily motivated by a study of the currently available resource allocation models for use in computer simulation of institutions of higher education. It was determined that existing models were based on an extremely gross or aggregated view of the resource process and thus could not provide a detailed simulation of the operation of a given school or department. Furthermore, no models had been formulated which could make direct and efficient use of the so-called "basic" or "hard" data compiled by the University from enrollment information, faculty and staff service reports, and standard accounting records.

A second factor which motivated the research arose from many discussions the author had with College and University administrators early in the research period. It was observed that considerable effort was being expended by the University to build an improved computer-based information system. Since the operational details of this system were under development by the University, it was clear that the data base requirements of a new resource allocation model could be used beneficially to guide the development of the University's information system.

As the survey of the literature continued, it became clear that most previous modeling efforts had been rather narrow in scope. Models which had been developed for allocation studies at a certain level of aggregation were not flexible in the sense that a simple modification of the models would allow a more detailed analysis, if desired. To provide "inherent" flexibility in the model and to establish a direct tie to simulation models used widely in the analysis and design of physical systems, the system theory concepts of "component structure" and state-space format were used. These concepts yield several important advantages. First, by using the component model approach, an individual school or department may be studied in a very detailed manner making use of the data base for that unit. Second, the separate (school) models can be easily combined within the computer to allow a more aggregated analysis of an entire college if desired. Finally, the state-space format allows a real time simulation to be effected which can adequately represent time transitions of student populations and the normal time delays of system responses to policy changes.

The component structure concept was also used to separate the model into two sectors; namely the student and production sectors. The student sector model developed in Chapter IV describes the student population distribution among the various schools and levels of study, the demands for credit hours of instruction imposed by College students, and the values attributed to these students based upon the costs of credit hours of instruction taken.

The production sector model, formulated in Chapter V, describes input-output models and unit cost equations for instruction, research, and extension for each school in the College.

The system model of the College is obtained by combining, through constraint equations, the two sector models as described in Chapter VI. This aggregated model displays the interesting interaction between the student and production sectors due to the use of graduate and student assistants in the instructional and research programs.

The model is designed to be computer implementable, but it should be recognized that a substantial programming effort will be required to bring the model into active practical use. Such an effort was not planned as a part of this research. However, to give at least some direction to a subsequent computer implementation and to indicate the nature of the data base required, two computer programs were developed. The first program establishes the student sector population model from enrollment transition data and the second program generates personnel resources and object expenditures, input-output parameters, unit costs, and total costs for individual courses. These programs were documented with postulated data and are described in the Appendix.

Conclusions

The primary objective of the research reported in this dissertation was to develop an improved university resource allocation model. The specific features of the new model which distinguish it from previous models are as follows:

1. The model is designed to make use of basic information already available in a typical university; e.g., student enrollment cards, faculty and staff service reports and university accounting records.

2. The model is capable of simulating the detailed resource allocation associated with a single department and evaluating costs for individual courses and specific research and extension activities.

3. By considering the standard departmental model as a component model in a more complex system, a model of the entire college system can be established taking into account student population transitions within and between individual schools and into and out of the college as a whole.

4. The model is capable of providing standard data currently used by administrators, regents and the legislature in evaluating the cost and quality of college activities. Moreover, the model, when implemented, can provide new data items not now available.

5. The general form of the model, allowing for arbitrary dimensions of student population vectors, personnel and expenditure vectors, etc. provides for a direct extension of the model to other departments or colleges of the University.

6. By utilizing the state-variable approach to the simulation, the model is in convenient form for the future application of more sophisticated analysis and prediction techniques.

By citing the list above, the author does not mean to imply that the model developed during this research is optimum. Clearly, much additional time and effort will be required to fully implement the model and it is expected that modifications will result from the implementation. The modeling of a complex process involving hundreds of variables related in non-obvious ways requires many subjective decisions on the relative significance of variables, the cost of their measurement, and the most useful units of measurement.

Added to the problem is the desire to impose linearity upon the variable relationships without really having data to substantiate or negate this assumption. The total implementation of the model with valid data is the only way in which the author's decisions and assumptions may be judged.

In spite of these uncertainties, it can be concluded that a practical modeling approach has been used and the resulting model is feasible and flexible. In addition, this research will have a beneficial effect on the University's development of a computer-based information system. Finally, and more generally, the unique nature of this research within an engineering discipline will hopefully act as a catalyst to encourage future research by engineers in educational systems.

Recommendations for Further Study

There are a number of desirable investigations related to this research that should be considered. Some of the more important are: 1) continued development of the exact nature of the data base to implement this model and serve future models as well; 2) testing the model against historical records to evaluate the basic linear assumptions; 3) collecting sufficient past data in order to make the model probabilistic and thus useful in making predictions; 4) extending the model to include the entire University. The model presented in this dissertation could serve as a prototype for models of the other colleges; 5) conducting behavioral analyses to determine the effect of financial aid upon student enrollment, reasons for student departures from the College or University, why students choose a particular major, why students decide to pursue an advanced degree, etc. It would be desirable to identify those factors which influence student enrollment and thus might be considered control variables; 6) studying techniques for the most equitable distribution of indirect (overhead) costs is certainly a desirable extension of this study.

There are other more general studies that would be desirable, such as changing the mix of resources utilized in the instruction program and observing the resulting quality of education according to some measure.

It should be apparent that the above recommendations for further study will require interdisciplinary research effort. No single discipline is sufficiently broad to effectively analyze a complex socio-economic system such as a college or university. Thus, the joint effort of researchers in education, computer science, accounting, engineering, and the behavioral sciences will be needed.

BIBLIOGRAPHY

1. "50% Rise Seen in School Money." Air Force Times, July 24, 1968, B8.

2. The Daily Oklahoman, Vol. 78, No. 25, January 30, 1969, 1-2.

3. Better Utilization of College Teaching Resources ... a Summary Report. New York: The Fund for the Advancement of Education, 1959, 10-11.

4. Faculty Teaching Loads and Student-Credit-Hour Costs. Oklahoma City: Oklahoma State Regents for Higher Education, State Capital, 1968.

5. Davis, R. G. Planning Human Resource Development. Chicago: Rand McNally & Co., 1966, 137-165.

6. Zabrowski, E. K., J. R. Zinter, and T. Okada. Student-Teacher Population Growth Model. Office of Education, U. S. Department of Health, Education, and Welfare, 1967.

7. Stone, R. Mathematics in the Social Sciences and Other Essays. Cambridge: The MIT Press, 1966.

8. Merk, J. W. "A Markovian Model for Projecting Movements of Personnel Through a System." No. PRL-TR-65-6. Lackland Air Force Base, Texas: Aerospace Medical Division, 1965.

9. 360 Gasp III Generalized Academic Simulation Program. Cambridge: Massachusetts Institute of Technology, 1967.

10. O'Brien, R. J. "Cost Model for Large Urban Schools." Technical Note No. 30. Office of Education, U. S. Department of Health, Education, and Welfare, 1967.

11. "Simulation of College Operations on IBM 1130." Computers in Education, Issue No. 6, 1968.

12. Raphael, D. L. "Applications of Complex Behavioral Models to Regional and Organizational Analysis." The Journal of Industrial Engineering, Vol. XVIII, No. 1, 1967, 123-130.

13. Koenig, H. E., M. G. Keeney, and R. Zemach. "A Systems Approach to Higher Education." Final Report, Project C-396. East Lansing, Mich.: Michigan State University, 1967.

14. Koenig, H. E., M. G. Keeney, and R. Zemach. "A Systems Model for Management, Planning, and Resource Allocation in Institutions of Higher Education." Final Report, Project C-518. East Lansing, Mich.: Michigan State University, 1968.

15. Physical Facilities for Higher Education in Oklahoma. Oklahoma City: Oklahoma State Regents for Higher Education, State Capital, 1964, 67.

16. Russell, J. D. The Finance of Higher Education, Revised. Chicago: The University of Chicago Press, 1954, 145.

17. Newman, M. "Matrix Calculations." A Survey of Numerical Analysis. Ed. J. Todd. New York: McGraw-Hill Book Company, Inc., 1962, 224.

18. Faddeev, D. K. and V. N. Faddeeva. Computational Methods of Linear Algebra. San Francisco, 1963, 113.

19. Harris, Seymour E. Higher Education: Resources and Finance. New York: McGraw-Hill Book Company, Inc., 1962, 503-504.

20. Morrell, L. R. "A Fresh Look at College Accounting." College and University Business, Vol. 44, No. 1, 1968, 46-48.

21. "A Study of Methods Used in Unit-Cost Studies in Higher Education." Bulletin No. 3. National Committee on Standard Reports for Institutions of Higher Education, 1932.

22. Van Dyke, G. E. and O. H. Levine. "Methods Used by 40 Dental Schools in Allocating Indirect Expenditures." College and University Business, Vol. 14, No. 5, 1953, 22-25.

APPENDIX

COMPUTER PROGRAMS

Introduction

Two computer programs used in this study are presented in this Appendix. The first program was used to implement Equation 4.2 and is now documented and available from the Computer Center Library. The second program demonstrates Equations 5.7 and 5.9. Both programs are written in FORTRAN IV language.

Student Population Program

The first program implements a set of first-order difference equations which describe the changes in student enrollment from one time period to the next. The equation simulated is:

$$\underline{s}(t)_{N\times 1}=U(t)_{N\times N}\underline{s}(t-1)_{N\times 1}+V(t)_{N\times N1}\underline{p}(t-1)_{N1\times 1}+W(t)_{N\times N2}\underline{q}(t-1)_{N\times 1} \quad . \qquad (A.1)$$

A discussion of Equation A.1 (i.e. Equation 4.2) is presented in Chapter IV and a listing of the program simulating this equation is provided in Table I. Output from this program is given in Table II and a listing of input data is described in Table III.

The program listed in Table I performs the following operations. It first computes the entires of the matrices and vectors on the right-hand-side of Equation A.1 (with the exception of $\underline{s}(t-1)$ whose values are given by input data). The program then multiplies the matrices times the corresponding vectors and thus determines $\underline{s}(t)$. The program then iterates one time period. The equation now simulated is:

$$\underline{s}(t+1) = U(t+1)\underline{s}(t) + V(t+1)\underline{p}(t) + W(t+1)\underline{q}(t) \quad . \tag{A.2}$$

$\underline{s}(t+1)$, calculated from Equation A.2, is the predicted student population for time period t+1 obtained by using the values for $\underline{s}(t)$ just calculated and the previous values for the other matrices and vectors.

In the first program listing, the following designation is used:

$$ST = \underline{s}(t)$$
$$U = U(t)$$
$$STM1 = \underline{s}(t-1)$$
$$V = V(t)$$
$$PTM1 = \underline{p}(t-1)$$
$$W = W(t)$$
$$QTM1 = \underline{q}(t-1)$$
$$STP1 = \underline{s}(t+1) \quad .$$

The sample output data of Table II was obtained for the input data listed in Table III. The simulation describes transitions for 3 schools in the College each with 6 student levels (N=18). Three types of new arrivals from off-campus (N1=3) and seven origins of transfers from on-campus (N2=7) are assumed. It should be noted that the values for N, N1, and N2, respectively are easily changed in the program by changing their values on the first data card listed in Table III (Format 3I5).

The matrix L describes the actual number of students remaining in the College from one time period to the next. Thus the first column of L indicates that five students who were in category 1 during the previous time period, i.e. t-1 are still in category 1 during time period t.

Also, three students transitioned from category 1 to 2 and one student transitioned from category 1 to 7.

The number of newly arriving students from off-campus of three types that enroll in the College at time t is described by L1. The first row of L1 shows that five students of type 1, one type 2 student, and no students of type 3 enrolled in category 1 at time t.

L2 is similar to L1 and describes the number of transfer students from on-campus that enroll in the College at time t.

The matrix U is calculated from L by dividing all entries in column j of L by the corresponding j^{th} row entry of STM1. Thus, the entry u_{ij} of U represents the proportion of continuing College students that were in category j at time t-1 and are in category i at time t. Similarly, V and W are obtained from L1 and L2, respectively, by dividing all entries in columns j of these matrices by the corresponding j^{th} row entries of PTM1 and QTM1 respectively.

S(T) is the student enrollment calculated for time t and S(T+1) is the predicted student enrollment at time t+1.

The only restriction on the student population program is that the maximum dimension of any array or vector is 30. This is easily changed by changing the DIMENSION statement and by also changing NDIM on the first executable statement of the program. The only control card required by the program is the "4" card and this card is placed directly before the "$IBSYS" card.

The first data card contains the values of N, N1, and N2 in Format (3I5). The next card or cards contains the values of the column vector $\underline{s}(t-1)$ in Format (26F3.0). The cards which follow the values of $\underline{s}(t-1)$ contain the values of STYPE, OSCLAS, and NSCLAS in Format (I1,2I2).

STYPE (student type) is 1, 2, or 3 depending upon whether a student is continuing in the College, a new arrival from off-campus, or a transfer from on-campus, respectively. Thus, a value of 1 for STYPE denotes that OSCLAS and NSCLAS are used to determine U. If STYPE equals 2, then OSCLAS (old student classification) and NSCLAS (new student classification) are used to determine V and PTM1. Also, if STYPE equals 3, OSCLAS and NSCLAS are used to determine W and QTM1. Finally, a value of STYPE equal to 4 indicates the end of the data set.

It should be noted that the values for OSCLAS will range from 1 to N for STYPE equal to 1, 1 to N1 for STYPE equal to 2, and 1 to N2 for STYPE equal to 3. The values of NSCLAS range from 1 to N.

Course Cost Program

The program listed in Table IV determines input vectors, input-output values, costs per student-credit-hour, and individual course costs according to the procedure established in Equations 5.7 and 5.9. Output for this program is given in Table V and a listing of the input data for the simulation is presented in Table VI.

A simulation was run assuming 2 schools, 2 course levels in each school, and two courses at each course level. However, the program will allow 100 schools, 10 course levels, and the number of courses is limited only by storage capacity and computer processing time.

The following designations are used in Table IV.

CSCHL = Course school

CNUMB = Course number

POIDEN = Personnel or Object expenditure identifier

OLDCS = Old course school

OLDCN = Old course number

SCH = Number of student-credit-hours produced

FTE = Full-time equivalent semester effort

DFTE = Dollars per full-time-equivalent

OEXP = Object expenditures per semester

POTYPE = Personnel or Object expenditure type

LAST = Last input data card

M2 = M^{j2}

M3 = M^{j3}

M4 = M^{j4}

M5 = M^{j5}

M6 = M^{j6}

M7 = M^{j7}

A(J) = $\underline{a}^{ij}(t)$

AH(J) = $\underline{a}^{j}(t)$

A1(J) = A^{1jkn} $(k=1,\ldots,6;\ n=1,\ldots,N_{jk})$

E(J) = $\underline{e}^{ij}(t)$

EH(J) = $\underline{i}^{j}(t)$

E1(J) = E^{1jkn} $(k=1,\ldots,6;\ n=1,\ldots,N_{jk})$.

Faculty, staff, graduate and student assistants vectors are designated similar to that above for administration.

The only control card required is the "999" card that is placed before the "$IBSYS" card. 999 appears in columns 34-36.

The values of CSCHL and CNUMB that appear on the 2nd data card must be given on the first and second executable statements of the program, respectively. The first data card provides the values of M2, M3, M4, M5, M6, and M7, respectively, in Format (6I2) and thus these values are easily changed. CSCHL, CNUMB, POIDEN, SCH, FTE, DFTE, OEXP, POTYPE, and LAST have a Format of (I2, I4, I1, 2F5.1, 2F7.2, I2, and I3). The data cards, excluding the first and last, must be sorted according to CSCHL and CNUMB before running the program.

The output data provided in Table V for school 1, course number 1024 will now be discussed. The first 5 entries of the column vector indicate individual administrator effort per student-credit-hour produced for the course. Entries 6 through 11 indicate individual faculty effort per SCH, entries 12-16 denote staff effort per SCH, entries 17-21 describe graduate assistant effort per SCH, entries 22-26 indicate student assistant effort per SCH, and entries 27-28 denote object expenditures per SCH.

ASUM, FSUM, RSUM, GSUM, USUM, and ESUM denote, respectively, administrative costs, faculty costs, staff costs, graduate assistant costs, student assistant costs, and object expenditures per SCH. TCOST denotes total course cost and CSCH denotes cost per SCH.

TABLE I

PROGRAM TO SIMULATE STUDENT TRANSITIONS

```
$JOB 2515-40047 VAUGHN GRACE
C     STUDENT POPULATION MODEL
      INTEGER STYPE,OSCLAS
      REAL PTM1,L,L1,L2,PROD
      DIMENSION ST(30 ),U(30 ,30 ),STM1(30 ),V(30 ,30 ),PTM1(30 ),
     1W(30 ,30 ),QTM1(30 ),STP1(30 ),L(30 ,30 ),L1(30 ,30 ),L2(30 ,30 )
     1,PROD(30),DATA(20)
C
C     TO CHANGE DIMENSION SIZE -- CHANGE SIZES OF ALL ARRAYS IN THE
C     DIMENSION STATEMENT ABOVE EXCEPT THE ARRAY DATA, THEN CHANGE THE
C     VALUE OF NDIM IN THE FIRST EXECUTABLE STATEMENT
C
      NDIM = 30
C
C     ZERO OUT THE ARRAYS AND VECTORS
C
      DO 3 I = 1,NDIM
      QTM1(I) = 0
      ST(I) = 0
      STM1(I) = 0
      PTM1(I) = 0
      STP1(I) = 0
      DO 3 J = 1,NDIM
      U(I,J) = 0
      V(I,J) = 0
      W(I,J) = 0
      L (I,J) = 0
      L1(I,J) = 0
3     L2(I,J) = 0
C     SINCE THIS IS THE FIRST TIME THROUCH SET NCOUNT = 1
C
C     READ THE NUMBER OF ROWS OF THE STM1 VECTOR, THE NUMBER OF COLUMS
C     OF V, AND THE NUMBER OF COLUMS OF W
C
1     FORMAT(3I5)
      READ(5,1) N,N1,N2
C
C     IF ANY OF THE SPECIFIED DIMENSIONS ARE TO LARGE PRINT AN ERROR MESSAGE
      MAXDIM = MAX0(N,N1,N2)
      IF(MAXDIM.GT.NDIM) WRITE(6,111) MAXDIM,NDIM
111   FORMAT(1H1,'        **** ERROR--A DIMENSION OF ',I5,' WAS SPECIFIED
     1 ON THE FIRST DATA CARD, THE MAXIMUM DIMENSION IS ',I5,' ****',//)
C
C     READ THE ENTRIES OF THE STM1 VECTOR
C
      READ (5,2) (STM1(I),I=1,N)
2     FORMAT(26F3.0)
4     FORMAT(I1,2I2,T1,20A4)
C
C     NOW READ THE MATRIX CARDS
C
15    READ(5,4) STYPE,OSCLAS,NSCLAS,DATA
      MAXDIM = MAX0(OSCLAS,NSCLAS)
C
C     IF STYPE IS GREATER THAN 4 PRINT AN ERROR MESSAGE
      IF(STYPE.GT.4)  WRITE(6,112) DATA
C
C     IF OSCLAS AND/OR NSCLAS ARE LARGER THAN THE MAXIMUM DIMENSION PRINT
C     AN ERROR MESSAGE
      IF(MAXDIM.GT.NDIM) WRITE(6,113) DATA
```

TABLE I (Continued)

```
112   FORMAT(1H ,'     **** ERROR--STYPE WAS GREATER THAN 4 -- DATA CARD
     1FOLLOWS ****',/,1X,20A4)
113   FORMAT(1H ,'     **** ERROR--OSCLAS AND/OR NSCLAS IS LARGER THAN DI
     1MENSION SIZE --DATA CARD FOLLOWS****',/,1X,20A4)
C     IF STYPE IS 1 USE FOR ARRAY L, IF STYPE IS 2 USE FOR ARRAY L2,
C     IF STYPE IS 3 USE FOR ARRAY L3, IF STYPE IS 4 THIS IS THE END OF
C     THE DATA SET
      GO TO (11,12,13,14),STYPE
C     NOW INCREMENT THE ELEMENT OF THE PROPER ARRAY WHICH APPEARS
C     IN THE NSCLAS ROW AND THE OSCLAS COLUMN
11    L (NSCLAS,OSCLAS) = L (NSCLAS,OSCLAS) + 1
      GO TO 15
12    L1(NSCLAS,OSCLAS) = L1(NSCLAS,OSCLAS) + 1
      PTM1(OSCLAS) = PTM1(OSCLAS) + 1
      GO TO 15
13    L2(NSCLAS,OSCLAS) = L2(NSCLAS,OSCLAS) + 1
      QTM1(OSCLAS) = QTM1(OSCLAS) + 1
      GO TO 15
C
C     FIND THE U,V,W ARRAYS
C
14    DO 16 I = 1,N
      DO 16 J = 1,N
16    U(I,J) = L(I,J)/STM1(J)
      GO TO 30
28    DO 29 I = 1,N
      DO 29 J = 1,N
29    U(I,J) = L(I,J)/ST(J)
30    DO 17 I = 1,N
      DO 17 J = 1,N1
17    V(I,J) = L1(I,J)/PTM1(J)
      DO 18 I = 1,N
      DO 18 J = 1,N2
18    W(I,J) = L2(I,J)/QTM1(J)
C
C     FIND S(T) BY ADDING ENTRIES OF CORRESPONDING ROWS OF L,L1, AND L2 ARRAYS
C
      DO 19 I = 1,N
      SL = 0
      SL1 = 0
      SL2 = 0
      DO 20 J = 1,N
20    SL = SL + L(I,J)
      DO 21 J = 1,N1
21    SL1 = SL1 + L1(I,J)
      DO 22 J = 1,N2
22    SL2 = SL2 + L2(I,J)
19    ST(I) = SL + SL1 + SL2
      WRITE(6,104) N, N
104   FORMAT(1H1,///,'          L IS A ',I2,' X ',I2,' MATRIX WITH THE FOLL
     1OWING ENTRIES',///)
      DO 34 I = 1,N
34    WRITE(6,105) (L(I,J),J=1,N)
105   FORMAT(1H0,30(1X,F4.1))
      WRITE(6,107) N,N1
107   FORMAT(1H1,///,'         L1 IS A ',I2,' X ',I2,' MATRIX WITH THE FOLL
     1OWING ENTRIES',///)
      DO 35 I = 1,N
35    WRITE(6,105) (L1(I,J),J=1,N1)
      WRITE(6,106)N,N2
```

TABLE I (Continued)

```
 106     FORMAT(1H1,///,'        L2 IS A ',I2,' X ',I2,' MATRIX WITH THE FOLL
        1OWING ENTRIES',///)
         DO 36 I = 1,N
 36      WRITE(6,105) (L2(I,J),J=1,N2)
         WRITE(6,108)N,N
 108     FORMAT(1H1,///,'         U IS A ',I2,' X ',I2,' MATRIX WITH THE FOLL
        1OWING ENTRIES',///)
         DO 37 I = 1,N
 37      WRITE(6,105) (U(I,J),J=1,N)
         WRITE(6,109)N,N1
 109     FORMAT(1H1,///,'         V IS A ',I2,' X ',I2,' MATRIX WITH THE FOLL
        1OWING ENTRIES',///)
         DO 38 I = 1,N
 38      WRITE(6,105) (V(I,J),J=1,N1)
         WRITE(6,110) N,N2
 110     FORMAT(1H1,///,'         W IS A ',I2,' X ',I2,' MATRIX WITH THE FOLL
        1OWING ENTRIES',///)
         DO 39 I = 1,N
 39      WRITE(6,105) (W(I,J),J=1,N2)
         WRITE(6,100) N
 100     FORMAT(1H1,///,'         S(T) IS A ',I2,' X 1 COLUMN VECTOR WITH TH
        1E FOLLOWING ENTRIES',///)
         DO 32 I = 1,N
 32      WRITE(6,101) ST(I)
 101     FORMAT(1H ,20X,F10.3)
C
C        NOW FIND S(T+1) USING THE OLD U,V,W MATRIX AND P AND Q VECTORS
 23      DO 27 I = 1,N
         SL1 = 0
         SL2 = 0
         PROD(I) = 0
         DO 24 J = 1,N
 24      PROD(I) = PROD(I) + U(I,J)*ST(J)
         DO 25 J = 1,N1
 25      SL1 = SL1 + L1(I,J)
         DO 26 J = 1,N2
 26      SL2 = SL2 + L2(I,J)
 27      STP1(I) = PROD(I) + SL1 + SL2
         WRITE(6,102) N
 102     FORMAT(1H1,///,'       S(T+1) IS A ',I2,' X 1 COLUMN VECTOR WITH TH
        1E FOLLOWING ENTRIES',///)
         DO 33 I = 1,N
 33      WRITE(6,101) STP1(I)
         WRITE(6,103)
 103     FORMAT(1H1,//////)
         STOP
         END

$ENTRY
```

TABLE II

SAMPLE OUTPUT DATA FOR STUDENT POPULATION PROGRAM

L IS A 18 X 18 MATRIX WITH THE FOLLOWING ENTRIES

5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
3.0	6.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0
0.0	0.0	0.0	9.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
0.0	0.0	0.0	0.0	2.0	9.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
1.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
0.0	1.0	0.0	0.0	0.0	0.0	2.0	9.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0
0.0	1.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	8.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	7.0

TABLE II (Continued)

L1 IS A 18 X 3 MATRIX WITH THE FOLLOWING ENTRIES

5.0	1.0	0.0
0.0	1.0	1.0
0.0	2.0	1.0
0.0	2.0	2.0
0.0	1.0	2.0
0.0	2.0	2.0
3.0	0.0	0.0
0.0	0.0	1.0
0.0	3.0	1.0
0.0	1.0	2.0
0.0	1.0	0.0
0.0	1.0	0.0
2.0	0.0	0.0
0.0	0.0	0.0
0.0	2.0	1.0
0.0	1.0	1.0
0.0	1.0	3.0
0.0	1.0	3.0

L2 IS A 18 X 7 MATRIX WITH THE FOLLOWING ENTRIES

4.0	0.0	0.0	0.0	0.0	3.0	0.0
4.0	0.0	4.0	0.0	0.0	0.0	0.0
0.0	4.0	4.0	0.0	0.0	0.0	0.0
0.0	0.0	4.0	1.0	0.0	0.0	0.0
4.0	4.0	0.0	0.0	0.0	1.0	0.0
0.0	0.0	0.0	3.0	0.0	0.0	0.0
4.0	4.0	2.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	6.0
4.0	0.0	0.0	0.0	3.0	0.0	0.0
0.0	8.0	0.0	0.0	0.0	0.0	0.0
4.0	4.0	2.0	1.0	0.0	0.0	0.0
0.0	0.0	8.0	0.0	3.0	0.0	0.0
0.0	8.0	4.0	2.0	0.0	0.0	0.0
4.0	0.0	0.0	2.0	0.0	0.0	4.0
4.0	4.0	0.0	0.0	3.0	0.0	0.0
0.0	0.0	8.0	0.0	1.0	0.0	0.0
4.0	0.0	4.0	1.0	0.0	0.0	0.0
4.0	4.0	0.0	0.0	0.0	0.0	0.0

TABLE II (Continued)

U IS A 18 X 18 MATRIX WITH THE FOLLOWING ENTRIES

0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
0.3	0.6	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
0.0	0.0	0.0	0.0	0.2	0.9	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1
0.1	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
0.0	0.1	0.0	0.0	0.0	0.0	0.2	0.9	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.1	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0
0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.7

TABLE II (Continued)

V IS A 18 X 3 MATRIX WITH THE FOLLOWING ENTRIES

0.5	0.0	0.0
0.0	0.0	0.0
0.0	0.1	0.0
0.0	0.1	0.1
0.0	0.0	0.1
0.0	0.1	0.1
0.3	0.0	0.0
0.0	0.0	0.0
0.0	0.1	0.0
0.0	0.0	0.1
0.0	0.0	0.0
0.0	0.0	0.0
0.2	0.0	0.0
0.0	0.0	0.0
0.0	0.1	0.0
0.0	0.0	0.0
0.0	0.0	0.1

W IS A 18 X 7 MATRIX WITH THE FOLLOWING ENTRIES

0.1	0.0	0.0	0.0	0.0	0.8	0.0
0.1	0.0	0.1	0.0	0.0	0.0	0.0
0.0	0.1	0.1	0.0	0.0	0.0	0.0
0.0	0.0	0.1	0.1	0.0	0.0	0.0
0.1	0.1	0.0	0.0	0.0	0.3	0.0
0.0	0.0	0.0	0.3	0.0	0.0	0.0
0.1	0.1	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.6
0.1	0.0	0.0	0.0	0.3	0.0	0.0
0.0	0.2	0.0	0.0	0.0	0.0	0.0
0.1	0.1	0.0	0.1	0.0	0.0	0.0
0.0	0.0	0.2	0.0	0.3	0.0	0.0
0.0	0.2	0.1	0.2	0.0	0.0	0.0
0.1	0.0	0.0	0.2	0.0	0.0	0.4
0.1	0.1	0.0	0.0	0.3	0.0	0.0
0.0	0.0	0.2	0.0	0.1	0.0	0.0
0.1	0.0	0.1	0.1	0.0	0.0	0.0
0.1	0.1	0.0	0.0	0.0	0.0	0.0

TABLE II (Continued)

S(T) IS A 18 X 1 COLUMN VECTOR WITH THE FOLLOWING ENTRIES

20.000
20.000
20.000
20.000
20.000
20.000
20.000
20.000
20.000
20.000
20.000
20.000
20.000
20.000
20.000
20.000
20.000
20.000

S(T+1) IS A 18 X 1 COLUMN VECTOR WITH THE FOLLOWING ENTRIES

27.000
30.000
29.000
31.000
28.000
33.000
27.000
33.000
29.000
29.000
28.000
28.000
24.000
30.000
26.000
29.000
27.000
28.000

TABLE III

SAMPLE INPUT DATA FOR STUDENT POPULATION PROGRAM

```
  18    3    7
 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
10101
10101
10101
10101
10101
11301
11301
10102
10102
10102
10202
10202
10202
10202
10202
10202
10702
10303
10303
10303
10303
10303
10303
10303
11503
11503
10404
10404
10404
10404
10404
10404
10404
10404
10404
10904
10904
10505
10505
10505
10505
10505
10505
10505
11705
10506
10506
10606
10606
10606
10606
10606
10606
10606
10606
10606
11106
11806
10107
10707
```

TABLE III (Continued)

10707	11414	20302	30203	30313
10707	11414	20303	30205	30313
10707	11414	20304	30205	30316
10707	11515	20304	30205	30316
11307	11515	20305	30205	30316
10208	11515	20305	30207	30316
10708	11515	20306	30207	30316
10708	11515	20306	30207	30316
10808	11515	20308	30207	30316
10808	11616	20309	30210	30316
10808	11616	20310	30210	30317
10808	11616	20310	30210	30317
10808	11616	20315	30210	30317
10808	11616	20316	30210	30317
10808	11616	20317	30210	30404
10808	11616	20317	30210	30406
10808	11616	20317	30210	30406
11308	11616	20318	30211	30406
10309	11717	20318	30211	30411
10309	11717	20318	30211	30413
10909	11717	30101	30211	30413
10909	11717	30101	30213	30414
10909	11717	30101	30213	30414
10909	11717	30101	30213	30417
10909	11717	30102	30213	30509
10909	11118	30102	30213	30509
10909	11818	30102	30213	30509
11010	11818	30102	30213	30512
11010	11818	30105	30213	30512
11010	11818	30105	30215	30512
11010	11818	30105	30215	30515
11010	11818	30105	30215	30515
11010	11818	30107	30215	30515
11010	20101	30107	30218	30516
11010	20101	30107	30218	30601
11010	20101	30107	30218	30601
11111	20101	30109	30218	30601
11111	20101	30109	30302	30605
11111	20107	30109	30302	30708
11111	20107	30109	30302	30708
11111	20107	30111	30302	30708
11111	20113	30111	30303	30708
11111	20113	30111	30303	30708
11711	20201	30111	30303	30708
11212	20202	30114	30303	30714
11212	20203	30114	30304	30714
11212	20203	30114	30304	30714
11212	20204	30114	30304	30714
11212	20204	30115	30304	4
11212	20205	30115	30307	
11212	20206	30115	30307	
11212	20206	30115	30311	
11313	20209	30117	30311	
11313	20209	30117	30312	
11313	20209	30117	30312	
11313	20210	30117	30312	
10214	20211	30118	30312	
10714	20212	30118	30312	
11414	20215	30118	30312	
11414	20215	30118	30312	
11414	20216	30203	30312	
11414	20217	30203	30313	
11414	20218	30203	30313	

TABLE IV

PROGRAM TO CALCULATE UNIT COSTS AND COURSE COSTS

```
$JOB 2515-40047 VAUGHN GRACE
C     PROGRAM TO CALCULATE INDIVIDUAL COURSE COSTS
      INTEGER CSCHL,CNUMB,POIDEN,OLDCS,OLDCN,POTYPE
      DIMENSION A(20),AH(20),A1(20),F(50),FH(50),F1(50),R(50),RH(50),
     1R1(50),G(50),GH(50),G1(50),E(50),EH(50),E1(50),U(50),UH(50),U1(50)
C     SET OLDCS AND OLDCN EQUAL TO CSCHL AND CNUMB RESPECTIVELY ON FIRST
      OLDCS=1
      OLDCN=1024
      READ(5,7) M2,M3,M4,M5,M6,M7
    7 FORMAT(6I2)
C     INITIALIZE VECTORS
      DO 20 J=1,M2
      A(J)=0.0
      AH(J)=0.0
      A1(J)=0.0
   20 CONTINUE
      DO 21 J=1,M3
      F(J)=0.0
      FH(J)=0.0
      F1(J)=0.0
   21 CONTINUE
      DO 22 J=1,M4
      R(J)=0.0
      RH(J)=0.0
      R1(J)=0.0
   22 CONTINUE
      DO 23 J=1,M5
      G(J)=0.0
      GH(J)=0.0
      G1(J)=0.0
   23 CONTINUE
      DO 24 J=1,M6
      U(J)=0.0
      UH(J)=0.0
      U1(J)=0.0
   24 CONTINUE
      DO 25 J=1,M7
      E(J)=0.0
      EH(J)=1.0
      E1(J)=0.0
   25 CONTINUE
      ASUM=0.0
      FSUM=0.0
      RSUM=0.0
      GSUM=0.0
      USUM=0.0
      ESUM=0.0
    1 READ(5,2) CSCHL,CNUMB,POIDEN,SCH,FTE,OFTE,DEXP,POTYPE,LAST
    2 FORMAT(I2,I4,I1,2F5.1,2F7.2,I2,I3)
      IF(LAST.EQ.999) GO TO 50
      IF(CSCHL.NE.OLDCS) GO TO 70
      IF(CNUMB.NE.OLDCN) GO TO 70
   11 OLDCS=CSCHL
      OLDCN=CNUMB
      OSCH=SCH
      IF(POIDEN.EQ.1) GO TO 90
      IF(POIDEN.EQ.2) GO TO 91
      IF(POIDEN.EQ.3) GO TO 92
      IF(POIDEN.EQ.4) GO TO 93
      IF(POIDEN.EQ.5) GO TO 94
```

TABLE IV (Continued)

```
      IF(POIDEN.EQ.6) GO TO 95
   90 A(POTYPE)=FTE
      AH(POTYPE)=DFTE
      GO TO 1
   91 F(POTYPE)=FTE
      FH(POTYPE)=DFTE
      GO TO 1
   92 R(POTYPE)=FTE
      RH(POTYPE)=DFTE
      GO TO 1
   93 G(POTYPE)=FTE
      GH(POTYPE)=DFTE
      GO TO 1
   94 U(POTYPE)=FTE
      UH(POTYPE)=DFTE
      GO TO 1
   95 E(POTYPE)=OEXP
      GO TO 1
   70 DO 101 J=1,M2
      A1(J)=A(J)/OSCH
  101 CONTINUE
      DO 102 J=1,M3
      F1(J)=F(J)/OSCH
  102 CONTINUE
      DO 103 J=1,M4
      R1(J)=R(J)/OSCH
  103 CONTINUE
      DO 104 J=1,M5
      G1(J)=G(J)/OSCH
  104 CONTINUE
      DO 105 J=1,M6
      U1(J)=U(J)/OSCH
  105 CONTINUE
      DO 106 J=1,M7
      E1(J)=E(J)/OSCH
  106 CONTINUE
      WRITE(6,3) OLDCS,OLDCN
    3 FORMAT(10X,'SCHOOL',I3,10X,'COURSE NUMBER',I5/)
      WRITE(6,108)
  108 FORMAT(1X,'FULL-TIME-EQUIVALENT OR OBJECT EXPENDITURE PER STUDENT-
     1CREDIT-HOUR'//)
  301 FORMAT(35X,F7.4)
      DO 300 J=1,M2
      WRITE(6,301) A1(J)
  300 CONTINUE
      DO 302 J=1,M3
      WRITE(6,301) F1(J)
  302 CONTINUE
      DO 303 J=1,M4
      WRITE(6,301) R1(J)
  303 CONTINUE
      DO 304 J=1,M5
      WRITE(6,301) G1(J)
  304 CONTINUE
      DO 305 J=1,M6
      WRITE(6,301) U1(J)
  305 CONTINUE
      DO 306 J=1,M7
      WRITE(6,301) E1(J)
  306 CONTINUE
```

TABLE IV (Continued)

```
      DO 201 J=1,M2
      ACOST=-(A1(J)*AH(J))
      ASUM=ASUM+ACOST
  201 CONTINUE
      DO 202 J=1,M3
      FCOST=-(F1(J)*FH(J))
      FSUM=FSUM+FCOST
  202 CONTINUE
      DO 203 J=1,M4
      RCOST=-(R1(J)*RH(J))
      RSUM=RSUM+RCOST
  203 CONTINUE
      DO 204 J=1,M5
      GCOST=-(G1(J)*GH(J))
      GSUM=GSUM+GCOST
  204 CONTINUE
      DO 205 J=1,M6
      UCOST=-(U1(J)*UH(J))
      USUM=USUM+UCOST
  205 CONTINUE
      DO 206 J=1,M7
      ECOST=-(E1(J)*EH(J))
      ESUM=ESUM+ECOST
  206 CONTINUE
      CSCH=ASUM+FSUM+RSUM+GSUM+USUM+ESUM
      TCOST=CSCH*DSCH
      WRITE(6,602)
  602 FORMAT(6X,'ASUM',6X,'FSUM',6X,'RSUM',6X,'GSUM',6X,'USUM',6X,
     1'ESUM',6X,'TCOST',6X,'CSCH')
      WRITE(6,207) ASUM,FSUM,RSUM,GSUM,USUM,ESUM,TCOST,CSCH
  207 FORMAT(1X,8F10.2/)
      DO 311 J=1,M2
      A(J)=0.0
      AH(J)=0.0
      A1(J)=0.0
  311 CONTINUE
      DO 312 J=1,M3
      F(J)=0.0
      FH(J)=0.0
      F1(J)=0.0
  312 CONTINUE
      DO 313 J=1,M4
      R(J)=0.0
      RH(J)=0.0
      R1(J)=0.0
  313 CONTINUE
      DO 314 J=1,M5
      G(J)=0.0
      GH(J)=0.0
      G1(J)=0.0
  314 CONTINUE
      DO 315 J=1,M6
      U(J)=0.0
      UH(J)=0.0
      U1(J)=0.0
  315 CONTINUE
      DO 316 J=1,M7
      E(J)=0.0
      E1(J)=0.0
  316 CONTINUE
```

TABLE IV (Continued)

```
      ASUM=0.0
      FSUM=0.0
      RSUM=0.0
      GSUM=0.0
      USUM=0.0
      ESUM=0.0
      GO TO 11
   50 DO 401 J=1,M2
      A1(J)=A(J)/OSCH
  401 CONTINUE
      DO 402 J=1,M3
      F1(J)=F(J)/OSCH
  402 CONTINUE
      DO 403 J=1,M4
      R1(J)=R(J)/OSCH
  403 CONTINUE
      DO 404 J=1,M5
      G1(J)=G(J)/OSCH
  404 CONTINUE
      DO 405 J=1,M6
      U1(J)=U(J)/OSCH
  405 CONTINUE
      DO 406 J=1,M7
      E1(J)=E(J)/OSCH
  406 CONTINUE
      WRITE(6,3) OLDCS,OLDCN
      WRITE(6,407)
  407 FORMAT(1X,'FULL-TIME-EQUIVALENT OR OBJECT EXPENDITURE PER STUDENT-
     1CREDIT-HOUR'//)
      DO 411 J=1,M2
      WRITE(6,301) A1(J)
  411 CONTINUE
      DO 413 J=1,M3
      WRITE(6,301) F1(J)
  413 CONTINUE
      DO 414 J=1,M4
      WRITE(6,301) R1(J)
  414 CONTINUE
      DO 415 J=1,M5
      WRITE(6,301) G1(J)
  415 CONTINUE
      DO 416 J=1,M6
      WRITE(6,301) U1(J)
  416 CONTINUE
      DO 417 J=1,M7
      WRITE(6,301) E1(J)
  417 CONTINUE
      DO 501 J=1,M2
      ACOST=-(A1(J)*AH(J))
      ASUM=ASUM+ACOST
  501 CONTINUE
      DO 502 J=1,M3
      FCOST=-(F1(J)*FH(J))
      FSUM=FSUM+FCOST
  502 CONTINUE
      DO 503 J=1,M4
      RCOST=-(R1(J)*RH(J))
      RSUM=RSUM+RCOST
  503 CONTINUE
      DO 504 J=1,M5

      GCOST=-(G1(J)*GH(J))
      GSUM=GSUM+GCOST
  504 CONTINUE
      DO 505 J=1,M6
      UCOST=-(U1(J)*UH(J))
      USUM=USUM+UCOST
  505 CONTINUE
      DO 506 J=1,M7
      ECOST=-(E1(J)*EH(J))
      ESUM=ESUM+ECOST
  506 CONTINUE
      CSCH=ASUM+FSUM+RSUM+GSUM+USUM+ESUM
      TCOST=CSCH*DSCH
      WRITE(6,602)
      WRITE(6,207) ASUM,FSUM,RSUM,GSUM,USUM,ESUM,TCOST,CSCH
      STOP
      END

$ENTRY
```

TABLE V

SAMPLE OUTPUT DATA FOR COURSE COST PROGRAM

SCHOOL 1 COURSE NUMBER 1024

FULL-TIME-EQUIVALENT OR OBJECT EXPENDITURE PER STUDENT-CREDIT-HOUR

0.0000
0.0000
0.0000
0.0000
0.0000
0.0025
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0015
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
1.0000
0.5000

ASUM	FSUM	RSUM	GSUM	USUM	ESUM	TCOST	CSCH
0.00	-15.00	0.00	-3.00	0.00	-1.50	-1950.00	-19.50

SCHOOL 1 COURSE NUMBER 1313

FULL-TIME-EQUIVALENT OR OBJECT EXPENDITURE PER STUDENT-CREDIT-HOUR

0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0017
0.0011
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0014
0.0000
0.0000
0.0000
0.0000
0.8333
0.1111

ASUM	FSUM	RSUM	GSUM	USUM	ESUM	TCOST	CSCH
0.00	-17.78	0.00	0.00	-2.08	-0.94	-1872.50	-20.81

TABLE V (Continued)

SCHOOL 1 COURSE NUMBER 2124

FULL-TIME-EQUIVALENT OR OBJECT EXPENDITURE PER STUDENT-CREDIT-HOUR

0.0004
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0017
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0006
0.0006
0.0000
0.0000
1.0417
0.0000

ASUM	FSUM	RSUM	GSUM	USUM	ESUM	TCOST	CSCH
-2.92	-10.83	0.00	0.00	-2.50	-1.04	-2075.00	-17.29

SCHOOL 1 COURSE NUMBER 2232

FULL-TIME-EQUIVALENT OR OBJECT EXPENDITURE PER STUDENT-CREDIT-HOUR

0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0021
0.0021
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
1.5000
1.8333

ASUM	FSUM	RSUM	GSUM	USUM	ESUM	TCOST	CSCH
0.00	-25.83	0.00	0.00	0.00	-3.33	-1750.00	-29.17

TABLE V (Continued)

SCHOOL 2 COURSE NUMBER 1022

FULL-TIME-EQUIVALENT OR OBJECT EXPENDITURE PER STUDENT-CREDIT-HOUR

0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0060
0.0020
0.0000
0.0000
0.0000
0.0020
0.0020
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000

ASUM	FSUM	RSUM	GSUM	USUM	ESUM	TCOST	CSCH
0.00	0.00	-40.00	-8.00	0.00	0.00	-2400.00	-48.00

SCHOOL 2 COURSE NUMBER 1413

FULL-TIME-EQUIVALENT OR OBJECT EXPENDITURE PER STUDENT-CREDIT-HOUR

0.0008
0.0000
0.0000
0.0000
0.0000
0.0017
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0008
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000

ASUM	FSUM	RSUM	GSUM	USUM	ESUM	TCOST	CSCH
-5.67	-10.00	0.00	-1.67	0.00	0.00	-2080.00	-17.33

TABLE V (Continued)

SCHOOL 2 COURSE NUMBER 2022

FULL-TIME-EQUIVALENT OR OBJECT EXPENDITURE PER STUDENT-CREDIT-HOUR

0.0000
0.0008
0.0008
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
1.2500
0.6250

ASUM	FSUM	RSUM	GSUM	USUM	ESUM	TCOST	CSCH
-10.78	0.00	0.00	0.00	0.00	-1.88	-2025.00	-12.66

SCHOOL 2 COURSE NUMBER 2724

FULL-TIME-EQUIVALENT OR OBJECT EXPENDITURE PER STUDENT-CREDIT-HOUR

0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0018
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0004
0.0007
0.0000
0.0000
0.0000
0.0000
0.0000

ASUM	FSUM	RSUM	GSUM	USUM	ESUM	TCOST	CSCH
0.00	-12.14	0.00	0.00	-2.14	0.00	-2000.00	-14.29

TABLE VI

SAMPLE INPUT DATA FOR COURSE COST PROGRAM

```
050605050502
0110242100.0.250 6000.00        01
0110244100.0.150 2000.00        01
0110246100.0             100.00 01
0110246100.0              50.00 02
0113132 90.0.150 6000.00        02
0113132 90.0.100 7000.00        03
0113135 90.0.125 1500.00        01
0113136 90.0              75.00 01
0113136 90.0              10.00 02
0121241120.0.050 7000.00        01
0121242120.0.200 6500.00        04
0121245120.0.075 2000.00        02
0121245120.0.075 2000.00        03
0121246120.0             125.0001
0122322 60.0.125 6400.00        05
0122322 60.0.125 6000.00        06
0122326 60.0              90.0001
0122326 60.0             110.0002
0210223 50.0.300 5000.00        01
0210223 50.0.100 5000.00        02
0210224 50.0.100 2000.00        01
0210224 50.0.100 2000.00        02
0214131120.0.100 6800.00        01
0214132120.0.200 6000.00        01
0214134120.0.100 2000.00        03
0220221160.0.125 7000.00        02
0220221160.0.125 6800.00        03
0220226160.0             200.0001
0220226160.0             100.0002
0227242140.0.250 6800.00        02
0227245140.0.050 2000.00        01
0227245140.0.100 2000.00        02
                                  999
```

VITA

Vaughn Kenneth Grace

Candidate for the Degree of

Doctor of Philosophy

Thesis: A SYSTEM MODEL FOR UNIVERSITY RESOURCE ALLOCATION

Major Field: Electrical Engineering

Biographical:

Personal Data: Born in Hopewell, Pennsylvania, September 6, 1936, the son of Robert W. and Grace H. Grace.

Education: Attended high school in Saxton, Pennsylvania, and graduated from Saxton-Liberty High School in May, 1954; graduated from the Naval Academy Preparatory School in June, 1957; received the Bachelor of Science degree in General Engineering from the United States Naval Academy in June, 1961. Commissioned as an officer in the United States in June, 1961. Continuous active duty in the United States Air Force from June, 1961 to the present. Current rank is Captain. Received the Master of Science degree in Electrical Engineering from Oklahoma State University in August, 1963; graduated from Squadron Officers School in August, 1965; completed requirements for the Doctor of Philosophy at Oklahoma State University in August, 1969.

Professional Experience: Private First Class, U. S. Army Reserve from December, 1954 to February, 1956; Communications Technician, U. S. Navy from February, 1956 to June, 1957; Midshipman, United States Naval Academy from June, 1957 to June, 1961. Served as a Project Officer for research and development in the Air Force Systems Command from August, 1963 to August, 1966.

Professional Organizations: Member of Eta Kappa Nu and the Institute of Electrical and Electronic Engineers.