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THE APPLICATION OF AN OPTIMAL DECISION-MAKING MODEL WITHIN A HIGHER EDUCATION SUBSYSTEM

by

Dale Cornish Cooper

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Dissertation Adviser

APPROVAL PAGE

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COOPER, DALE CORNISH. The Application of an Optimal Decision-Making Model Within a Higher Education Subsystem. (1977) Directed by: Dr. Donald W. Russell. Pp. 77.

Resource planning has become a fundamental activity of administrators at all levels in higher education. The decision-making process which surrounds the creation and justification of budgets can clearly benefit from the application of systems analysis and quantitative methods. Such techniques not only force a decision maker to set up an explicit priority system of goals, but these techniques show how optimally to achieve such goals within a set of limiting conditions (constraints).

The resource management model developed here is a single-period linear goal programming model with a multi-objective non-Archimedean structure used in connection with the computer program MPSX and a prepackaged linear program, SIMPLEX. A planning horizon was limited to a time span of one year and involved only one of the schools in a medium-size urban university. Computer runs revealed that the "ideal" mix of faculty, assistants, and staff necessary to satisfy student credit hour demand would require the doubling of the salary budget, and was infeasible. Other ordering of priorities indicated the best faculty, assistants, and staff mix within constraints.

The model requires that administrators be capable of defining, quantifying, and ordering objectives. This requirement is probably the most serious shortcoming faced by administrators. University administrators and faculty must be certain they are ready for the planning process that requires careful measurement of various objectives that some have considered unquantifiable heretofore.

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Suggestions for future research included a recommendation that efforts be directed toward the conceptualization of more effective multiperiod models. It was also recommended that in order to improve performance by the implementation of multiperiod models, the systems approach should be used to study the decision process, the information flow, the data base, and the structure of the organization to determine how models and techniques might be used to achieve optimal results in a higher education subsystem.

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CHAPTER I

INTRODUCTION

The idea of a university itself as a formal, organized institution is a medieval innovation, which contrasts with the Greek schools and with the organizational precedents in ancient Alexandria and in the Byzantine and Arabian cultures. (Kast & Rosenzweig, 1974) As a base for this study, it is essential that the evolution of the university from a simple organizational structure to its present complex form be investigated and understood before trying to find a technique whereby all resources of the university and its various schools and departments would be conserved and expended in an optimal manner.

Evolution of the University Organization

By the twelfth century in Europe, the church not only was supreme as a ruler of man's conscience, but also exercised great power over his mundane affairs. Early in the thirteenth century there began a shift of temporal power away from the church and toward political states and kings. The church hierarchy then moved bring its scattered organizations such as the religious orders, cathedral chapters, and universities, under more effective papal control. (Rashdall, 1936)

The church lawyers looked back to Roman law and its concept of corporations as fictitious legal entities. The investigations of the lawyers into the Roman law led to the famous proclamation of Pope Innocent IV. The central idea in the Innocentean doctrine was that each cathedral chapter, collegiate church, religious fraternity, and university constituted a "universitas," a free corporation. Its corporate personality was not something natural in the sense of a social reality, but rather "an artificial notion invented by the sovereign for convenience of legal reasoning," existent only in the contemplation of law. (Perkins, 1973)

The efforts of the papacy, the need of universities for protection against the immediate threats to their freedom from local bishops and townspeople, and the fact that the kings also intruded on university sovereignty supported the corporate idea. The theory of corporate existence meant ultimately the end of the guild system and, for universities, of the idea of an independent association of scholars. During the latter part of the thirteenth century, Emperor Frederick II rivaled Pope Gregory IX in the issuance of grants of authorization to universities. (Hull, 1971)

University Growth and Expansion of Functions

As the university increased in size, various tasks were necessary for corporate operation. It was recognized that there was a need to keep some rudimentary form of records for faculty use and future reference. This function fell to the "beadle."

Other officers that came into being in the medieval administration were the dean, the treasurer, and the registrar. By 1309 most of these officers were firmly established within the university organization and were permanent, elected officials. It soon became necessary to have some method of making policy decisions affecting the university as a whole beyond the institution itself. Within the Italian universities there developed a system where civil authorities appointed boards of control. Scottish institutions developed external boards of control made up of members not related to the institution. (Hull, 1971)

By the fifteenth century, "university" was synonymous with "studium generale," a place where students gathered. The evolution of the term is illustrative of the still prevailing idea that the central purpose of the university is to be a body of men gathered together as scholars where knowledge is preserved, transmitted, and investigated. (Rashdall, 1936)

Scholars and students began to gather in groups of more than just one to one. Now the scholar had to decide which students would be permitted to study with him. For the period of study to come to fruition, a terminal point was necessary. Thus, the office of chancellor came into being. The chancellor was responsible only to the Roman Catholic Church. He alone could grant degrees and could make arbitrary and final decisions about who would receive such degrees and when. The license to teach was primarily used to prepare a scribe to work within the church, or as an indication that the chancellor was of the opinion that the holder was qualified to lecture and teach others. (Hull, 1971)

Students and faculty became organized into separate bodies. The total body of faculty and students felt the need to have one individual to represent their corporate concerns. This person came to be called the rector. The rector was selected by faculty vote, by student vote, or by vote of the proctors. The rector was a symbol of representative administration. (Munro, 1922)

The concept of corporations matured in England during the fifteenth and sixteenth centuries. It provided an effective legal means by which the king, and later Parliament, could delegate authority for designated activities. This concept of governmental grant of authority served as the basis for the charters and statutes of the colleges of the English universities. This included a head elected by the teaching staff or fellows, and a formal body constituted of these fellows which "exercised the legislative powers." (Davis, 1961)

The Organizational Form of the Colonial Universities

The influence of this English college model was evident in the founding of the first two colonial colleges, Harvard [1636] and William and Mary [1693]. Both of these institutions were formed with governing councils composed of internal members [the president and teaching fellows] with external supervising boards that held final approval powers and the right of visitation. (Quincy, 1860)

Another medieval precedent came to the colonies with the early settlers and caused a significant modification of the English practice. In place of immediate control of the colleges by the teachers or professors, the practice evolved of granting complete corporate power to governing boards composed of external members. The origins of the use of external control lie in the medieval universities of northern Italy. (Rashdall, 1936)

The English pattern of internal control by academics which was followed by Harvard and William and Mary did not set the precedent for university government in this country. That distinction fell to Yale College, established in 1701. The founders of Yale, possibly because of influences from the European Calvinistic practices, petitioned for a single nonacademic board of control. (Brody, 1935)

Another deviation from English precedent also began to emerge. The right of the king and Parliament to grant a charter carried with it an equal right to withdraw this charter.

The Impact of John Locke's Philosophy on Universities

In the eighteenth century, a new philosophy, formalized by John Locke, gained acceptance in the American colonies. This view stressed the nature of government as an agreement among individuals, with sovereignty held by the people. Thus, corporations gained protection from legislative intrusions associated with the rights of individuals. Early in the nineteenth century, court decisions began to interpret charters as contracts equally binding upon the state and their recipients. (Perkins, 1973)

As a result of these rulings, and specifically the Dartmouth College case as tried by the Supreme Court, the state-college relationship was reexamined. Faced with a loss of control, legislators questioned the award of public funds to private corporations. As a result, there emerged a number of public or state colleges, but not as agencies of state government under ministers of education in the continential tradition. The early public colleges took the form of public corporations parallel in their general organization to the private colleges. (Wright, 1938)

In the nineteenth century, it became common practice for legislatures to delegate governing power over state institutions to boards of control, established as public corporations. These boards received authority to control property, contracts, finances, forms of internal governance, and relationships with internal personnel such as students, faculty, and administrative employees. (Brody, 1935)

The period from 1869-1900 indicates a gradual but decisive involvement of professors in academic policies. During this period, alumni also entered actively into the government of colleges and universities. The unique role of influence of presidents of universities should also be recognized. Every university to rise to major status did so under the dominating influence of presidential leaders. The typical college president was portrayed as the head of a personal college family, looking after the character of the students. The president also served as a clergyman, scholar and worker. (Rudolph, 1956)

Two shifts in organizational structure followed the change to a new set of goals for the university in America. By the turn of the century, departments and professional schools had become the basic units for academic affairs. The impact of the "new education" fitted the times, for it reflected a turning away from Christian theology as a basis for life's judgments and toward values oriented more to the marketplace and materialism. In contrast to the declining enrollment of the 1840s and 1850s, the latter half of the nineteenth century marked the beginning of what has become a constantly increasing rate of college attendance. More students meant more professors, more buildings, more facilities and equipment, and more money from private and public sources.

The departmental structure that followed in the wake of specialized knowledge was accompanied by professors assuming more control over academic affairs. As the department formalized, there came about the evolution of the "department chairman." The function of the department chairman was to bridge the gap between the university's daily operational needs and the faculty's specialized disciplines. (Cowley, 1964)

Faculties have created a hierarchy of departments and schools vested with a large variety of permanent and temporary committees. This bureaucracy claims rights of control over the totality of the academic function. (Katz & Kahn, 1966) Administrators have formed a separate hierarchy, or bureaucracy, to grapple with the immense tasks of management of essential, yet supportive, services which maintain the university, such as budget and finance. (Etzioni, 1964)

The different attitudes and values associated with each bureaucracy have driven a psychological wedge between faculty members and administrators. Specialization has produced a similar tendency toward fragmentation of the academic organization. The history of university organization to the twentieth century has been an account of the disintegration of the traditional form of government conceived in terms of formal authority granted to governing boards, which have exercised it through the president as executive officer.

The diffusion of government by means of dissipation of boards and presidential influence and dispersion of operating control to departments, administrative offices, and faculty governing bodies, has been accompanied by an intrusion of external forces. Professional and disciplinary associations, accrediting agencies, agencies of the federal government for all institutions, and state executive offices for public education have tended to bypass presidents and boards. (Cooke, 1910)

The movement toward decentralization of control over educational and administrative functions has begun to come up against external demands for more forceful central authority to the end of a more efficient use of resources. (Duryea, 1973)

University government had coalesced into the pattern we are familiar with shortly after the turn of the century. It reflected a continuation of medieval and English precedents where institutional autonomy received a high degree of protection. These precedents were modified in American higher education by a more overt sense of commitment to societal needs. Private colleges and universities had the protection afforded them by their status as corporations under the law. Each officer developed since the medieval period has come about in order to fulfill a specific function rather than to actualize goals of educational philosophies. (Hull, 1971)

The transformation of American universities into complex administrative systems came about in response to a need for the coordination and control of an expanding academic program. The need for administrative control grew out of the university's relationship with the general society. The university faced the problem with an intricate credit system for student admissions and educational accounting. Another factor, however, was the administrative organization of universities resulting from the managerial role of the American college president, and the fact that early founders looked to the colleges of the English universities for their patterns. (Parsons, 1968)

The major thrusts that have characterized the altered form of the university organization and brought about in any substantial way certain unique educational functions during the last sixty years are: (1) the expansion in numbers of both personnel and of units of the administrative structure, both academic and managerial; (2) the consolidation of departmental control over academic matters; (3) the diffusion of participation in government with a concurrent lessening of the influence of boards and presidents. (Perkins, 1973)

<u>The Diverse Roles and Functions of the University</u>

Higher education in the United States is characterized by a variety of organizations, with differing roles and functions within each organization. These institutions vary in size, location, length and level of programs. The student bodies are also heterogeneous, studying at various levels and with differing interests and objectives. The institutions are privately endowed or state or locally funded. (Leslie & Miller, 1974)

The social role of the university is the collection and dissemination of knowledge. This sets the broad role of the university, but does not indicate more specific goals and values. (Millett, 1962)

Teaching and scholarly research are the primary goals and technical tasks of the university. The academic staff---professors, associate professors, assistant professors, and instructors---performs these tasks and is the operating subsystem in the university organization. The teachers transmit knowledge to the students in specialized disciplines through the pursuit of scholarly and scientific research. (Kast & Rosenzweig, 1974) In addition to teaching and scholarly research, administrative technology must be available in the form of academic administration for the staff, student personnel services, business administration of daily operating activities, and public relations. The growing turbulence and complexity of society, coupled with unparalleled technological development, has focused the attention of the population on the importance of higher education. (Gross & Grambsch, 1974)

The rapidly rising expenditures for facilities and personnel in higher education has caused state legislatures to examine more closely and more critically the operations of these educational institutions. No longer can universities request large sums of money from the legislature and the paying public unless they are prepared to justify and defend each proposed expenditure. (Kaludis, 1973)

Decision making and mathematical models are developed and taught in university classes. However, the application of these techniques within the university has usually been neglected.

Statement of the Problem

This study was designed to apply a single-period goal programming model to one school in a medium-size urban university. A medium-size university refers to a university with a student body of approximately 10,000.

Purpose of the Study

Universities are experiencing stringent budgetary constraints, making it imperative that all resources of the university and its various schools and departments be conserved and expended in an effective manner. The basic purpose of this study was to aid optimal planning and decision making in one school in a medium-size urban university.

Definition of Terms

For the purpose of this study, several concepts assumed specific meanings:

1. Decision - the act of deciding or settling a dispute or question by providing judgment.

2. General Systems Theory - the existence of General Systems laws which apply to any system, irrespective of the particular properties of the system.

3. Goal Programming - a special extension of linear programming capable of handling decision problems which deal with a single goal with multiple subgoals, as well as problems with multiple goals with multiple subgoals, when there is no dimensional limitation of the objective function.

4. Input - any measurable event or series of events occurring outside the transformation area that influences the outputs.

5. Interface - the collection of inputs and outputs that links two subsystems.

6. Model - an abstract representation of a system which attempts to give "reality" a mathematical rather than a verbal expression. A model's primary purpose is to integrate data about the system's behavior in a way that provides information about the characteristics of that behavior.

7. Organization - a plurality of parts, each achieving specific objectives, maintaining themselves through their interrelatedness, simultaneously adapting to the external environment, and maintaining the interrelated state of the parts.

8. Output - any measurable event or series of events that are immediately determined by the transformation area.

9. Prepackaged program - a type of program previously prepared and tested for validity that may be drawn from the computer data bank much like a book from the library.

10. Single-period model - one which deals with one time period.

11. System - a set of interrelated elements, each of which is related directly or indirectly to every other element; connotes plan, method, order, or arrangement.

12. Subsystem - an element or related part of a system.

13. Theory - a set of assumptions from which can be derived by purely logico-mathematical procedures a larger set of empirical laws.

14. Transformation process - the conversion of input energy into a product form characteristic of the system.

15. Values - in a decision-making context, normative standards held by individual human beings of what human beings ought to desire; determinants and guidelines in decisions.

Delimitation of the Study

The scope of this study was confined to a review of the evolution of the university as an organization; the history of the development of the General Systems Theory, systems, subsystems, and models; and the application of a single-period goal-programming model to one school in a medium-size urban university.

Assumptions

1. That in a university setting, decision-making responsibilities are diffused.

2. That there was a need for more and varied information available for planning and decision making.

3. That with adequate data and the use of an appropriate model, in conjunction with digital computers, strategies for optimal decision making at the university, school, and department level can be formulated.

4. That by the employment of such optimal decision-making effort, the students, faculty, and administrative members of the school and university, and the taxpayers and contributors at large, would receive the benefits derived from the most efficient use of the available school and university resources.

CHAPTER II

REVIEW OF THE LITERATURE

This chapter will present a brief history of the development of the General Systems Theory, systems, and models, and will focus on the literature regarding the various aspects of discovery and progress made by various individuals in the formulation of these various concepts.

General Systems Theory

General systems theory is concerned with developing a systematic, theoretical framework for describing general relationships of the empirical world. This theory seeks to classify systems by the way their components are organized, or interrelated, and to derive the laws, or typical patterns of behavior, for the different classes of systems. An ultimate goal will be a framework which will tie all disciplines together in a meaningful relationship.

There has been some development of interdisciplinary studies. Areas such as social psychology, bio-chemistry, astrophysics, social anthropology, economic psychology, and economic sociology have been developed in order to emphasize the interrelationships of previously isolated disciplines.

There are various examples of the idea leading to a general systems theory. Sir Isaac Newton set forth the "system of the world."

Darwin, in his theory of evolution, integrated all life into a "system of nature" and indicated how the myriad of living subsystems were interrelated.

In his book, Keynes (1936) connected many complicated natural and man-made forces which make up the entire economy.

The modern philosopher of science, E. A. Singer, Jr., tried to see the whole picture and show the relationship between the various disciplinary points of view.

Ludwig von Bertalanffy (1964) recognized throughout the world as a pioneer in forwarding the organismic view in biology, and the role of symbol-making in the interpretation of human experience, is also acknowledged as a founder of general systems theory. In explaining his approach to the general systems theory, von Bertalanffy wrote:

> Systems theory is a broad view which far transcends technological problems and demands a reorientation that has become necessary in science in general and in the gamut of disciplines from physics and biology to the behavioral and social sciences and to philosophy. (p. 290)

In 1927, Kohler raised the postulate of a systems theory. He intended to elaborate the most general properties of inorganic compared to organic systems. This demand was met by the theory of open systems.

A biologist, Lotka (1925), came closest to the objective of a general systems theory by setting up the basic formulations.

Commoner (1971) defines the general systems theory in this manner:

> The First Law of Ecology: Everything is connected to everything else. It reflects the existence of the elaborate network of interconnections in the ecosphere among different living organisms, and between populations, species, and individual organisms and their physicochemical surroundings. (p. 33)

The role of the general systems theory was described by Walter Buckley in the following manner:

> A whole which functions as a whole by virtue of the interdependence of its parts is called a system, and the method which aims at discovering how this is brought about in the widest variety of systems has been called general systems theory. (Johnson, Kast, & Rosenzweig, 1973, p. 7)

The economist, Boulding, writing to von Bertalanffy in 1953 concerning his thoughts about the general systems theory, said:

> I seem to have come to much the same conclusion as you have reached, though approaching it from the direction of economics and the social sciences rather than from biology, that there is a body of what I have been calling "general empirical theory," or "general system theory" in your excellent terminology, which is of wide applicability in many different disciplines. (von Bertalanffy, 1964, p. 14)

Science has for two hundred years tried primarily to find, within the organism, whatever is simple. The same strategy of looking for the simple part has been used in physics and chemistry. (Ashby, 1958)

Sir Ronald Fisher was one of the first to realize that not all systems allow analysis of single parts. Fisher's problem was to get information about how the complex system of soil and plants would react to fertilizers by giving crops. One method of study was to analyze plant and soil into a host of little physical and chemical subsystems, get to know each subsystem individually, and then predict how the combined whole would respond. This method was too slow, Fisher decided. The information he wanted could be obtained by treating soil and plant as a complex whole. Thus, Fisher initiated a new scientific strategy. (Ashby, 1958)

The growth phenomena is found in practically all the sciences and even in most of the arts. It indicates that the theories of growth cut across most of the boundaries of the sciences.

Structural growth relates to general systems theory in that it consists of a complex structure of interrelated parts in which the growth process involves change in the relation of the parts. What grows is not the overall size of the structure, but the complexity or systematic nature of its parts. Structural growth includes such complex phenomena as the growth of crystal structures, the growth, division, and differentiation of cells, the growth of organizations, language, mental structures, and of societies.

As institutions grow, they have to maintain larger and larger specialized administrative structures in order to overcome the increasing difficulties of communication between the "edges" or outside surfaces of the organization and the central executive.

The universality of the principles set forth in regard to a general theory of growth indicate that perhaps there is emerging from the welter of the sciences something like a "General Systems Theory." (Boulding, 1956)

What general methods can general systems theory follow? Using one method, von Bertalanffy takes the world as he finds it, examines the various systems that occur in it, and then draws up statements about the regularities that have been observed to hold. The second method is to start at the other end. Instead of studying first one system, then a second system, etc., this method considers the set of all conceivable systems and then reduces the set to a more reasonable size. (von Bertalanffy, 1964)

In order that the interdisciplinary movement may not degenerate into undisciplined approaches, it is important that some structure be developed to integrate the various separate disciplines while retaining the type of discipline which distinguishes them.

One approach to providing an overall framework would be to pick out phenomena common to many different disciplines and to develop models which would include such phenomena. This is the general systems theory.

Philosophers and managers have long sought concepts and methods which fit any and all situations. What is needed is men who will not only seek to understand what it is they are about, but have the ability to recognize and understand their relationships in a total system. (Parsons, 1951)

The parallelism of general cognitive principles in different fields is even more impressive when one considers the fact that those developments took place independently. In addition, the general systems concept mostly developed without any knowledge of work and research in other fields. (Mather, 1951)

A number of developments have taken place intended to meet the needs of a general theory of systems. Some of these developments are:

1. Cybernetics, based upon the principle of feedback.

2. Information theory, with the concept of information as a measurable quantity.

3. Game theory, analyzing rational competition between two or more opponents for maximum gain and minimum loss.

4. Decision theory, analyzing rational choices within human organizations, based upon examination of a given situation and its possible outcomes.

5. Topology or relational mathematics, including non-metrical fields such as network and graph theory.

6. Factor analysis, of factors in multivariable phenomena in psychology and other fields. (von Bertalanffy, 1964)

The major aims of the general systems theory are:

1. To accelerate a general tendency toward integration in the various sciences, natural and social.

2. To utilize the general systems theory as an important means for aiming at exact theory in the nonphysical fields of science.

3. To develop unifying principles running "vertically" through the universe of the individual sciences, thus bringing us nearer to the goal of the unity of science.

Systems

A system is an organized, unitary whole composed of two or more interdependent parts, components, or subsystems and delineated by identifiable boundaries from its environmental suprasystem. (Kast & Rosenzweig, 1974)

Angyal defines a system as a logical genus suitable to the treatment of wholes, and may involve an unspecified number of members.

A set of interrelated elements, each of which is related directly or indirectly to every other element, and no subset is unrelated to any other subset, is defined as a system. (Ackoff & Emery, 1972)

Cleland and King (1972) define a system as a regularly interacting or interdependent group of items forming a unified whole.

According to Haimann and Scott (1974), a system is a set of interrelated, interdependent elements in which the function of each part fully depends on the other parts, which in turn rely on the element initially singled out.

Another definition of a system is a collection of elements---such as procedures, equipment, and persons---with a set of relations among them which are dictated by a common goal or goals.
(Fahey, Love, & Ross, 1969)

Strong and Smith (1968) indicate that to them a system is a group of interrelated elements placed together for the purpose of obtaining an objective common to each element.

A system is a set of objects with a given set of relationships between the objects and their attributes. Thus the system becomes a process in the linkage of objects and their attributes through relationships. (Optner, 1965)

Johnson, Kast, and Rosenzweig (1973) relate that a system is an array of components designed to accomplish a particular objective according to plan.

V. I. Kremyanskiy (1958) writing about certain peculiarities of organisms as a "system" from the point of view of physics and biology, discussed the theories of material systems as they pertain solely to actually existing associations. Associations of this type might properly be called unorganized systems. The more developed their internal and external connections, and the more complex the partial systems forming the material association, the more the whole is dependent upon the individual components. The more varied and complex the interconnections between systems or subsystems, the deeper the changes in the systems or subsystems. The essential features of the systems and subsystems can do more than change. They can be newly created through the creative capacities of the system or subsystem.

The environment includes the objects and changes which exert considerable influence on the material system without being a part of it. Material systems are called, according to their type of relationship with the environment, isolated, closed, or open. An isolated system is purely abstract and hypothetical. In a closed system, the exchange of elements and energy with the environment does not play an important role. In an open system, a periodic or continuous exchange of elements and energy with the environment is typical.

The relationship between the organizational orders of matter is determined by the organic systems of each succeeding order which contains the systems of the preceding order as its basic systems, not directly, but mainly as part of the subsystem.

For a system to be suitable for study by the physicist, no energy must enter or leave it, except as the experimenter directs. In the same way, the systems suitable for study in the biological world, while freely open to energy, must be closed to all sources of disturbance or variation, or entrophy, except as directed by the experimenter. (Kast & Rosenzweig, 1974)

The integrative function of the general systems theory may be summarized as a unitary concept of the world based on the isomorphy of laws in different fields. This means that the world, or the total of observable events, shows structural uniformities, manifesting themselves by isomorphic traces of order in the different levels. (Cleland & King, 1972)

Ackoff and Emery (1972) offer some definitions and key concepts to hang on the framework of the general systems theory. To these authors, a system is an entity which is composed of at least two elements and a relation that holds between each of its elements and at least one other element in the set. Each of a system's elements is connected to every other element, directly or indirectly.

An abstract system is one whose elements are concepts. Languages, philosophic systems, and number systems are examples. In an abstract system the elements are created by definition and the relationships between them are created by assumptions. Such systems are the subject of study of the formal sciences.

A second type of system is the concrete system, where at least two elements are objects. In concrete systems, establishment of the existence and properties of elements and the nature of relationships between them requires research with an empirical component in it. Such systems are the subject of study of the informal sciences.

The state-maintaining system is a system that can react in only one way to any one external or internal event, but it reacts differently to different external or internal events. These different reactions produce the same external or internal state outcome. Such a system only reacts to changes.

A goal-seeking system can respond differently to one or more different external or internal events in one or more different external or internal states and can respond differently to a particular event in an unchanging environment until it produces a particular outcome. This system has a choice of behavior and the behavior is responsive, but not reactive.

The multi-goal-seeking system is one that is goal-seeking in each of two or more different external or internal states, and seeks different goals in at least two different states, the goal being determined by the initial state.

A purposive system is a multi-goal-seeking system, the different goals of which have a common property. Production of that common property is the system's purpose. These types of system can pursue different goals, but they do not select the goal to be pursued. The goal is determined by the initiating event, and such a system chooses the means by which to pursue its goals. (Ackoff & Emery, 1972)

The purposeful system is one which can produce the same outcome in different ways in the same internal or external state and can produce different outcomes in the same and different states. Thus a purposeful system is one which can change its goals under constant conditions. It selects ends as well as means and thus displays will. Human beings are the most familiar examples of such systems.

An ideal-seeking system is a purposeful system which on attainment of any of its goals or objectives, then seeks another goal and objective which more closely approximates its ideal. An ideal-seeking system is one which has a concept of perfection or the ultimately desirable, and pursues it systematically. (Ackoff & Emery, 1972)

The function of a system is production of the outcomes that define its goals and objectives. To function is to produce the same outcome in different ways.

A system is adaptive if it reacts or responds by changing its own state and/or that of its environment so as to increase its efficiency with respect to that goal or goals.

The application of systems thinking has been of particular relevance to the social sciences. There is a close relationship between general systems theory and the development of functionalism in the social sciences. Functionalism attempts to look at social systems in terms of structures, processes, and functions, and attempts to understand the relationship between these components. (Parsons, 1968)

Modern economics has increasingly used the systems approach. Economics is moving away from static equilibrium models appropriate to closed systems toward dynamic equilibrium considerations appropriate to open systems.

Models

The objective of model-building is to construct a symbolic representation of the total system that will be useful in the empirical phases of research. (Feldman & Kanter, 1965)

Brightman, Luskin, and Tilton (1971) describe a model as a means of replicating real phenomena. For example, model airplanes are used by adult aircraft designers in wind tunnels to determine the characteristics of real aircraft when moving through air at various speeds. At the same time, the model airplane cannot hope to replicate every characteristic of the real thing.

A model, according to Haimann and Scott (1974), constitutes the most faithful representation of the operation or system possible. It is usually a simplified representation of reality.

Deutsch (1952) defines a model as a structure of symbols and operating rules which is supposed to match a set of relevant points in an existing structure of process.

A model is an abstract representation of a system which attempts to give reality a mathematical rather than a verbal expression in English or some other language. (Huse & Bowditch, 1973)

Strong and Smith (1968) discuss a model as it represents a real-world system or subsystem. The model is then manipulated in an attempt to improve the real situation which it represents. Models have long been used for training purposes. Maps serve as descriptive models to teach students the relative location of parts of the earth's surface. Models, in addition to training, are useful for improving the actual situation.

Model building and model use provide a framework for managing. Models provide a means for analyzing and synthesizing complex situations or systems. A typical step in the management science approach to problem solving is that of constructing a model to represent the system under study. (Forrester, 1961)

Thus model building, an abstract representation of a system, is one way to understand complex relationships and improve the quality of decision making. It permits experimentation among various decision strategies to test the results of assigning different values to the variables involved. (Price, 1968)

To the extent that models are appropriate representations, they can be extremely valuable in analysis and provide a systematic method for problem solving. The model becomes an orderly method by which to review and appraise alternative ways of using scarce resources to accomplish a particular objective. (Emshoff, 1971)

Considering the nature of a problem, the constantly changing environment in which planning must be formulated, and the limited resources and time available to complete a study, it becomes apparent why the logic of a systematic approach can assist and refine the decision-making process. (Johnson, Kast, & Rosenzweig, 1973)

Application of the Systems Approach to Higher Education

From a historical perspective, there have been several early papers calling for the application of systems analysis and quantitative methods to education. Such papers were written by Kershaw and McKean (1959), Platt (1962), and Schroeder and Rath (1965). Although these papers and others called for applications of quantitative techniques, little was accomplished until about 1965 when applications and research began to rapidly expand.

One of the earliest surveys of work in the field of higher education was conducted by Rath (1968). He traced the development of the field in several areas and indicated that a large part of the work prior to 1968 was on computerized class scheduling. Two other surveys, limited exclusively to modeling in higher education, are by Weathersby (1972), and Systems Research Group (1972). Weathersby's approach was to use the optimal control theory in a model which included decision variables of undergraduate admissions, faculty hiring, and new facilities over an n-period planning horizon. A differential dynamic programming approach was used to find decision variables which maximized the "value" achieved. The Systems Research Group worked with a model known as Computerized

Analytical Methods in Planning University Systems (CAMPUS) at the University of Toronto, Ontario, Canada. From enrollment inputs, CAMPUS developed activity workloads and the associated faculty, space, and equipment required. Activity loads are then computed from specified probabilities that a student in a given curriculum will engage in a particular activity. Appropriate activities are grouped by cost centers such as academic departments and by programs. After applying resource factors to the activity loads, the result was the resource requirements of the given input enrollments over future periods of time. Even though CAMPUS has been tested at several institutions, only limited usage to date has been achieved as a part of institutional management programs.

Clowes (1972) developed a simulation exercise that provided participants with an instructional model for learning to match types of decision issues with types of structures for decision-making. The simulation was tried with students of junior college administration and proved effective for developing competence in classifying both decision issues and structures for decision-making.

Another simulation model was developed by Gonzalez (1972) for the allocation of resources within a higher education subsystem. The model joined the calculations used in the manpower requirement and the rate of return and took into account the constraints on available resources found in the real world. Two contributions were made to the field of educational planning in that the model reconciled the manpower approach and the rate of return and it provided a methodology for the predication of future rates of return.

Kelso (1972) used a 43-item questionnaire containing the descriptions of decisions in five areas: (1) curriculum; (2) faculty personnel; (3) student affairs; (4) budgeting; and (5) building and plant. Respondents were asked to indicate which organizational level was authorized to make each of 43 decisions. Specific findings of the study were as follows: (1) there was more conflict between present and preferred policies for the lower levels of the organization than for higher ones; (2) there was disagreement among different organizational levels of the four colleges in the study regarding all decision areas except Student Affairs and Budgeting; (3) the most disagreement with regard to present policies occurred in the areas of Faculty Personnel and Curriculum; (4) there was disagreement among the five organizational levels regarding preferred policies in all five decision areas; and (5) the most disagreement with regard to preferred policies occurred in the areas of Faculty Personnel and Curriculum. The study indicated that there was consistently more severe disagreement on preferred policies for each decision area than for present policies. These results were used to indicate areas where decision making takes place.

Resource-planning is a fundamental activity of administration at all levels in universities and colleges. Resource allocation deals with allocating fixed amounts of resources among various activities. As an example, a resource allocation model may accept a university payroll budget as input and determine how it should be allocated between types of faculty, teaching assistants, and staff. (Schroeder, 1973)

Lee and Clayton (1972), Geoffrion, Dyer, and Feinberg (1972), and Schroeder (1973) developed models that dealt with resource allocation. These models all accept resources as inputs and allocate them to various activities, but they differ in the type of resources considered, level of aggregation, and model technology. They also are designed to answer different types of resource planning questions.

Resource management models can be classified into the following groups: (1) single-period or multiperiod; and (2) simulation or satisficing. Single-period models deal with one time period while multiperiod models consider the future effects of current decisions. Furthermore, single-period models consider resources as fixed. Simulation means to obtain the essence of, without reality. Satisficing refers to a good solution, not necessarily the optimal outcome preferred by the decision maker.

In higher education, when enrollments rise, there are many ways to adjust to instructional load without increasing faculty. Similarly, when enrollments drop, it should not necessarily require a corresponding and immediate reduction in faculty. What is needed is a relation that will indicate an increasing pressure for more faculty because of increasing enrollments, and similarly, an increasing pressure for less faculty when enrollments drop. Thus, a loose connection between faculty and enrollments will tend to allocate, but not require, more or less faculty as enrollments increase or decrease. One way to achieve this state is with a goal-oriented optimization model, or a satisficing model with faculty-to-student demand level as one of the goals and with penalties for deviating from the desired levels. Goal programming (GP) is a special extension of linear programming (Charnes and Cooper, 1961; Ijiri, 1965; Lee, 1972). This method is capable of handling decision problems which deal with a single goal with multiple subgoals, as well as problems with multiple goals with multiple subgoals (Ijiri, 1965). In the conventional linear programming method, the objective function is undimensional---either to maximize profits (effectiveness) or to minimize costs (sacrifice). The GP model handles multiple goals in multiple dimensions; therefore, there is no dimensional limitation of the objective function.

The satisficing model can aid the administrators of a higher education institution in two major areas. First, the model can determine how to allocate available funds among academic units considering goals for faculty, graduate assistants, and staff. In the second place, the model can answer "what if" questions regarding the impact of hiring levels on budgets, goal levels and other model parameters.

Often, goals set by the decision maker are achievable only at the expense of other goals. Furthermore, these goals may be incommensurable. Because of these factors, there is a need to establish a hierarchy of importance among these incompatible goals so that the lower order goals are considered only after the higher order goals are satisfied or have reached the point beyond which no further improvements are desirable. If the decision maker can provide an ordinal ranking of goals in terms of their contributions or importance to the organization, the problem can be solved by goal programming. The true value of goal programming is the solution of problems involving multiple, conflicting goals according to the administration's priority structure.

The term "administration", as used in the following chapter on research design and methodology, refers to the Dean, Department Chairmen, and senior faculty members of one school within a medium-size urban university.

CHAPTER III

RESEARCH DESIGN AND METHODOLOGY

This chapter discusses the research design and methodology utilized in this study. This discussion includes the procedure employed and a description of the model with the various parameters, variables, constraints and goals, as well as the method of data analysis.

Procedure

The researcher developed a single-period goal-programming model similar to that of Lee and Clayton (1972), but with a multi-objective non-Archimedean structure to be used in connection with the computer program Mathematical Programming System Extended (MPSX) which was developed by the International Business Machines Corporation (IBM). The model used a planning horizon limited to a time span of one year and involved only one of the schools in a medium-size urban university.

A prepackaged linear program, SIMPLEX, was available to the researcher through the Triangle Universities Computer Center (TUCC), located in the Research Triangle near Durham, Chapel Hill and Raleigh, North Carolina.

The various constraints on the operations of the school were formulated by the school administration, indicating the monetary budget, and existing faculty and staff personnel. Various goals, via target levels, were designated by the administration, and were incorporated into the model by the researcher. In addition, the administration ranked the goals in order of importance. The objective was the minimization of the sum of the deviations from specified target levels.

The necessary input for the model was in two areas: (1) the parameters to be measured, such as faculty/student ratio and faculty/staff ratio; and (2) the existing and proposed salary levels for various ranks of faculty, staff, and assistants.

After the data were compiled from the personnel records of the school, the data had to be processed in punched card form. The IBM 29 Keypunch machine in the Academic Computer Center was utilized for punching the data on cards. When the data had been keypunched on cards, the researcher used the Academic Computer Center IBM 370 Computer/Terminal to relay the data to TUCC and into SIMPLEX. The output was in the form of a printout via the Academic Computer Center printer equipment. The SIMPLEX program provided optimal mixes of various variables such as faculty, staff, and assistants, and at the same time indicated the costs of the mix.

There was also a sensitivity analysis performed on the parameters of the goal-programming model. Sensitivity is the study of the effects of changes in the parameters of the model on the optimality and/or feasibility of current optimal/feasible mix.

The Model

The notion of incommensurability (non-Archimedean structure) is expressed mathematically in the following manner:

A set of numbers $M_1, M_2, \ldots, M_k$ has the non-Archimedean property if $M_1 < M_2 < \ldots < M_k$ means that there exists no scalar number, c, such that $cM_1 > M_2$ or $cM_2 > M_k$. This property means that M_k is always greater than $M_1, M_2, \ldots, M_{k-1}$ and hence the event to which it attaches is always more important than the event to which M_1 or M_2 or ... or M_{k-1} attaches.

When the non-Archimedean property is applied to the goal-programming model, the following structure results:

$$\text{Minimize } d = M_1(d_1^+ + d_1^-) + M_2(d_2^+ + d_2^-) + \ldots + M_m(d_m^+ + d_m^-)$$

$$\text{Subject to: } \sum_{j=1}^{n} a_{ij}x_j + d_i^- - d_i^+ = g_i \qquad i = 1,2,\ldots,m$$

$$x_j \geq 0 \text{ for all } j$$

$$d_i^+, d_i^- \geq 0 \text{ for all } i$$

where x_j $(j=1,2,\ldots,n)$ denote the decision variables, d_i^+ and d_i^- denote over- and underachievements of goal i, the target level of which is specified by g_i.

Since the objective function possesses the non-Archimedean property, ordinary linear programming cannot be used to solve the problem. Thus, the following set of linear programming problems must be solved in succession:

$$\text{Minimize } d_1 = d_1^+ + d_1^-$$

Subject to: $\sum_{j=1}^{n} a_{ij}x_j + d_i^- - d_i^+ = g_i \quad i=1,2,\ldots,m$

$x_j,\ d_i^+,\ d_i^- \geq 0$ for all i and j

Let d_1* be the optimal value of d_1, then the second linear programming model is formulated:

Minimize $d_2 = d_2^+ + d_2^-$

Subject to: $\sum_{j=1}^{n} a_{ij}x_j + d_i^- - d_i^+ = g_i \quad i=1,2,\ldots,m$

$d_1^+ + d_1^- \leq d_1^*$

$x_j,\ d_i^+,\ d_i^- \geq 0$ for all i and j

The $m^{\underline{th}}$ linear programming model will have the following structure:

Minimize $d_m = d_m^+ + d_m^-$

Subject to: $\sum_{j=1}^{n} a_{ij}x_j + d_i^- - d_i^+ = g_i \quad i=1,2,\ldots,m$

$d_1^+ + d_1^- \leq d_1^*$

$d_2^+ + d_2^- \leq d_2^*$

$\vdots \qquad \vdots$

$d_{m-1}^+ + d_{m-1}^- \leq d_{m-1}^*$

$x_j,\ d_i^+,\ d_i^- \geq 0$ for all i and j

The solution process looked tedious, yet in reality m, the number of distinct priority or importance levels in the goal structure cannot be large, constrained usually in value to a number less than ten. Thus, only a few linear programming runs were needed. Furthermore, bounded variables technique could be used to eliminate the additional constraints as runs progress from one linear programming problem to the next.

For example, at the end of the first run, let d_i^{+*} and d_i^{-*} be the optimal values of d_1^{+} and d_1^{-}. Then, for the next run the constraint $d_1^{+} + d_1^{-} \leq d_1^{*}$ can be replaced by two upper-bound declarations on d_1^{+} and d_1^{-} using d_1^{+*} and d_1^{-*} for the upper-bound values. In addition, one linear programming problem may be linked to the next by feeding the output of one as an input to the other in one run.

Variables, Parameters, and Constraints

In the model, thirteen variables were used to generate the most satisficing strategy. In this case, most satisficing means the best faculty mix under the given circumstances. The variables are given in this section of the study and also listed again in the section dealing with the analysis of the data resulting from the various computer runs. In addition to the variables, there also follows a listing of the parameters and constraints utilized in the model.

<u>Variables</u>

x_1 = number of graduate research assistants (GRA)

x_2 = number of graduate teaching assistants (TA)

x_3 = number of full-time instructors (INS)

x_4 = number of "all-but-dissertation" faculty (ABD)

x_5 = number of assistant professors without terminal degree

x_6 = number of associate professors without terminal degree

x_7 = number of part-time instructors without terminal degree

x_8 = number of staff

x_9 = number of assistant professors with terminal degree

x_{10} = number of associate professors with terminal degree

x_{11} = number of full professors with terminal degree

x_{12} = part-time instructors with terminal degree

R = total payroll increase from prior budget year; comprised of faculty, staff, and graduate assistant salary increases

TP = total payroll budget for the fiscal year

Parameters

P_1 = percentage of the academic staff that is classified as full-time faculty

P_2 = percentage of the academic staff at the undergraduate level with terminal degree

P_3 = percentage of the academic staff at the graduate level with terminal degree

ud = estimated level of undergraduate student body demand measured in student credit hours

gd = estimated level of graduate student body demand measured in student credit hours

f:u = desired undergraduate faculty-to-student ratio

f:g = desired graduate faculty-to-student ratio

f:s = desired faculty-to-staff ratio

f:gra = desired faculty-to-graduate research assistant ratio

ucs = desired undergraduate class size

gcs = desired graduate class size

uhc = projected undergraduate "head-count"

ghc = projected graduate "head-count"

is_1 = desired percentage increase in salary for graduate assistants

is_2 = desired percentage increase in salary for faculty

is_3 = desired percentage increase in salary for staff

Parameters-Continued

cr_1 = average number of credit hours taken by a typical undergraduate in the school

cr_2 = average number of credit hours taken by a typical graduate student in the school

Maximum teaching loads, desired proportion of each category of faculty, and average annual salary for graduate assistants, faculty and staff are denoted in Table 1, a table of symbols:

TABLE 1

Symbols for Desired Proportion of each Category of Faculty, Maximum Teaching Loads, and Average Annual Salaries

		Teaching Loads		
Variable	Desired Proportion	Undergraduate	Graduate	Salary
x_1	dp_1	-	-	s_1
x_2	dp_2	t_2	-	s_2
x_3	dp_3	t_3	t_3'	s_3
x_4	dp_4	t_4	t_4'	s_4
x_5	dp_5	t_5	t_5'	s_5
x_6	dp_6	t_6	t_6'	s_6
x_7	dp_7	t_7	-	s_7
x_8	dp_8	-	-	s_8
x_9	dp_9	t_9	t_9'	s_9
x_{10}	dp_{10}	t_{10}	t_{10}'	s_{10}
x_{11}	dp_{11}	t_{11}	t_{11}'	s_{11}
x_{12}	dp_{12}	t_{12}	t_{12}'	s_{12}

Constraints

1. Accreditation Standards

a. A certain percentage of the academic staff must be full-time faculty:

Let F = total number of teaching staff $\left(\sum_{i=2}^{7} x_i + \sum_{i=9}^{12} x_i\right)$

Then, $$\sum_{i=3}^{6} x_i + \sum_{i=9}^{11} x_i \geq P_1 F$$

b. A certain percentage of the faculty available for undergraduate teaching is required to possess the terminal degree:

$$\sum_{i=9}^{12} x_i \geq P_2 F$$

c. A certain percentage of the faculty available for graduate teaching is required to possess the terminal degree:

$$\sum_{i=9}^{12} x_i \geq P_3 (F - x_2 - x_7)$$

2. Total Number of Teaching Staff Based on Student Demand

The model incorporated estimated levels of undergraduate and graduate student demand measured in student credit hours and the maximum teaching loads for faculty in the formulation of the following constraints:

a. $$\sum_{i=2}^{7} t_i x_i + \sum_{i=9}^{12} t_i x_i \geq ud \qquad \text{(undergraduate)}$$

where $ud = uhc(cr_1/ucs)$

Constraints-Continued

b. $$\sum_{i=3}^{7} t_i'x_i + \sum_{i=9}^{12} t_i'x_i \geq gd \qquad \text{(graduate)}$$

where $gd = gcs(cr_2/gcs)$

Another aspect to be considered in the determination of the size of teaching faculty was the desired faculty to student ratios at the undergraduate and graduate levels:

c. $$\sum_{i=2}^{7} x_i + \sum_{i=9}^{12} x_i \geq (f{:}u)uhc \qquad \text{(undergraduate)}$$

d. $$\sum_{i=3}^{6} x_i + \sum_{i=9}^{12} x_i \geq (f{:}g)ghc \qquad \text{(graduate)}$$

3. Distribution of Teaching Staff

It was necessary to impose constraints on the distribution of faculty within the school. The Dean, in collaboration with the senior faculty group members, decided on a schedule of desired proportions for each category of faculty. If no constraints were imposed, however, the resulting mix of faculty would probably be the most inexpensive one (i.e., a mix of mostly faculty without terminal degrees and part-time instructors, since the model would have no means of identifying the undesirableness of such a mix so long as the accreditation requirements were met).

$$x_i \leq dp_i \cdot F \quad \text{(maximum quotas)} \quad i=2,3,\ldots,7$$

$$x_i \geq dp_i \cdot F \quad \text{(minimum quotas)} \quad i=9,10,11,12$$

Constraints-Continued

4. Number of Nonacademic Staff

An adequate number of clerical staff is needed for the operation of an academic unit, thus the following constraint was imposed:

$$x_8 \geq (f{:}s)F$$

5. Number of Graduate Research Assistants

Faculty must have adequate research support to be able to generate research projects which are used in turn to measure professional quality of each faculty member. Thus, the following constraint was used:

$$x_1 \geq (f{:}gra).\sum_{i=3}^{6} x_i + \sum_{i=9}^{11} x_i$$

6. Annual Salary Increases

Annual salary increases are not only necessary to help the employed staff stay abreast of the yearly increases in the cost of living, but are essential to keep and maintain a professionally competent group of faculty and staff. Salary increases to faculty are tools to maintain compatibility within the current highly competitive markets for qualified faculty; thus,

$$is_1 \sum_{j=1}^{2} x_j + is_2\left(\sum_{j=3}^{7} x_j + \sum_{j=9}^{12} x_j\right) + is_3 x_8 - d^+ = R$$

where d^+ is the excess of total salary increases over the budgeted amount.

Constraints-Continued

7. Total Payroll Budget

The total payroll constraint was expressed as:

$$\sum_{i=1}^{12} s_i x_i + (R + d^+) \leq TP$$

An Applied Numerical Example

The data that were used in applying the goal-programming model to the school are given in Tables 2, 3, and 4. Average salary figures for the academic and nonacademic staff were not listed because of their confidential nature.

TABLE 2

Desired Proportions of Faculty

Variable	Minimum	Maximum
x_2	-	5%
x_3	-	5%
x_4	-	10%
x_5	-	0%
x_6	-	0%
x_7	-	5%
x_9	35%	-
x_{10}	25%	-
x_{11}	15%	-
x_{12}	-	0%

TABLE 3

Teaching Loads

Variable	Maximum Teaching Loads: Undergraduate	Maximum Teaching Loads: Graduate
x_2	6	-
x_3	12	-
x_4	6	3
x_5	6	3
x_6	6	3
x_7	6	-
x_9	6	3
x_{10}	3	3
x_{11}	-	6
x_{12}	3	3

TABLE 4

Values Used for Various Parameters

Parameter Name	Value Used
f:u	1:14
f:g	1:8
f:s	4:1
f:gra	2:1
ucs	30
gcs	20
uhc	1,857
ghc	667
is_1	1%
is_2	6%
is_3	6%
cr_1	9 hours
cr_2	6 hours

The applied constraints and the goals are listed below in the same order as they were presented in the previous section.

Constraints

1. Accreditation Standards

   The three stipulations in this group were considered as constraints rather than goals. The difference between the term "goals" and the term "constraints" is that the former represent the administrator's desires, whereas the latter represent the environment of his operation.

<u>Constraints-Continued</u>

However, in the mathematical formulation, the only difference is that the constraints must be satisfied before any attempt is made to meet the goals. In other words, constraints have a higher preemptive value than any of the goal preemptions incorporated in the model, even when they cannot be satisfied under the circumstances of conflicting or incompatible goals. In any event, the goals must be satisfied insofar as the constraints permit this to be attained. Thus, the three constraints in this group are formulated as follows:

a. At least 75% of the academic staff must be full-time faculty.

$$\sum_{i=3}^{6} x_i + \sum_{i=9}^{11} x_i \geq 0.75F$$

b. At least 60% of the faculty available for undergraduate teaching must possess the terminal degree.

$$\sum_{i=9}^{12} x_i \geq 0.60F$$

c. At least 75% of the faculty available for graduate teaching must possess the terminal degree.

$$\sum_{i=9}^{12} x_i \geq 0.75(F - x_2 - x_7)$$

Constraints-Continued

2. Total Number of Teaching Staff Based on Student Demand

Although the university and the school will attempt to meet the forecasted demand by undergraduate and graduate students in credit hours, shortages on the supply side will occur due to the limited amount of funds available for the hiring of additional faculty. For this reason, the following two expressions relate the "desires" of the administrators in the form of formulated goals:

$$6x_2 + 12x_3 + 6\sum_{i=4}^{7} x_i + 6x_9 + 3x_{10} + 3x_{12} + d_4^- - d_4^+ = 557$$

(undergraduate)

where d_4^- and d_4^+ are the deviation variables denoting the levels of underachievement and overachievement. Note that both variables cannot take on positive values at the same time since the same goal cannot be underachieved and overachieved at the same time. If $d_i^- = d_i^+ = 0$, then the goal is exactly satisfied. The demand at the undergraduate level was computed as prescribed earlier, so that 1,857(9/30) ≈ 557.

Similarly,

$$3\sum_{i=4}^{6} x_i + 3x_9 + 3x_{10} + 6x_{11} + 3x_{12} + d_5^- - d_5^+ = 200$$

(graduate)

Constraints-Continued

The goals pertaining to the desired faculty-to-student ratios are listed next:

$$\sum_{i=2}^{7} x_i + x_9 + x_{10} + d_6^- - d_6^+ = 130 \text{ (undergraduate)}$$

The target level of the goal is computed again as previously prescribed so that (1:14) (1,857) ≈ (0.07) (1,857) ≈ 130. The target level of the goal for the faculty-to-student ratio at the graduate level is computed similarly: (1:8) (667) ≈ (0.125) (667) ≈ 83. Thus, the goal is expressed as:

$$x_4 + \sum_{i=9}^{12} x_i + d_7^- - d_7^+ = 83 \quad \text{(graduate)}$$

3. Distribution of Teaching Staff

The desires of the Dean, as listed in Table 2, were used in formulating the following goals:

$$(0.05F - x_2) + d_8^- - d_8^+ = 0$$
$$(0.05F - x_3) + d_9^- - d_9^+ = 0$$
$$(0.10F - x_4) + d_{10}^- - d_{10}^+ = 0$$
$$x_5 - d_{11}^+ = 0$$
$$x_6 - d_{12}^+ = 0$$
$$(0.05F - x_7) + d_{13}^- - d_{13}^+ = 0$$
$$(0.35F - x_9) + d_{14}^- - d_{14}^+ = 0$$
$$(0.25F - x_{10}) + d_{15}^- - d_{15}^+ = 0$$
$$(0.15F - x_{11}) + d_{16}^- - d_{16}^+ = 0$$
$$x_{12} - d_{17}^+ = 0$$

Constraints-Continued

4. Number of Nonacademic Staff

A ratio of 4 to 1 was expressed as the desired faculty-to-staff ratio, and it is reflected in the following goal expression:

$$\left(\sum_{i=2}^{6} x_i + 0.5x_7 + \sum_{i=9}^{11} x_i + 0.5x_{12} - 4x_8\right) + d_{18}^- + d_{18}^+ = 0$$

A part-time instructor, with or without terminal degree (x_7 and x_{12}) was assumed to be equivalent to one-half of a full-time faculty member as far as demands for secretarial help were concerned.

5. Number of Graduate Research Assistants

The Dean expressed a desired ratio of 2:1; that is, one graduate research assistant for every two faculty members. Thus,

$$\left(\sum_{i=3}^{6} x_i + \sum_{i=9}^{11} x_i - 2x_1\right) + d_{19}^- - d_{19}^+ = 0$$

6. Annual Salary Increases

As listed in Table 4, it was decided to give a 1% salary increase to graduate assistants, and 6% increases to faculty and staff. The size of the increase in budget was quite meager ($16,000.00) and thus a budget overrun in this category was most definitely expected. The underachievement variable, d_{20}^-, is deleted from the goal expression since underspending the increase budget was

Constraints-Continued

neither feasible nor desirable.

$$0.01 \sum_{i=1}^{2} s_i x_i + 0.06 \sum_{i=3}^{12} s_i x_i - d_{20}^{+} = 16,000$$

7. Total Payroll Budget

The budget level for the year was set at \$816,000.

Thus, $$\sum_{i=1}^{12} s_i x_i + I \leq 816,000$$

where I is the total number of actual dollars to be spent on raises, thus $I = 16,000 + d_{20}^{+}$.

CHAPTER IV

RESULTS OF DATA ANALYSIS

This chapter summarizes the results obtained from the statistical analyses of the data.

Three different priority structures were applied to the goals formulated for the school. The relative importance attached to each category of goals is reflected via the preemptive priority attached to the category by the administrator.

In the first run, it was of great interest to the planners to find out what it would cost to satisfy all of the goals formulated for the school. The planners were quite certain that funds would not be sufficient to satisfy the student demand at the stipulated desired faculty-to-student ratios while maintaining the desired class sizes. In addition, extra funds would be needed to maintain the desired faculty-to-graduate research assistant and the faculty-to-staff ratios.

The cost of an ideal mix of faculty, staff, and graduate research assistants would be a valuable piece of information, especially for the Dean in his future requests for more funds from the central university administration. Comparisons between ideal and actual mixes could be efficiently used in future plans.

In the second run, a move back to reality was made by assigning an absolute ceiling on the amount of total funds that could be spent. In this run, a priority structure had to be constructed for the goals at hand to reflect the relative importance attached to the various goals. Thus, goals of secondary importance are to be attempted only after either goals of primary importance are fully satisfied or have reached points beyond which no improvements are possible under the given constraints.

Results of Computer Run 1

The following priorities were assigned to the goals for the first run:

a. Accreditation standards must be met.

b. Student demand in credit hours must be satisfied as closely as possible while maintaining the desired faculty-to-student ratios.

c. Faculty-to-staff ratio must be maintained.

d. Faculty-to-graduate research assistants ratio must be maintained as closely as possible.

e. The desired faculty distribution needs to be maintained.

In the results of the first computer run, the solutions were the results of rounding-off of the previous continuous solutions.

Results - First Run

Goals	Results
a. Accreditation	Achieved
b. Faculty/Student ratios	Achieved
c. Faculty/Staff ratio	Achieved
d. Faculty/Graduate Research Assistants ratio	Achieved
e. Faculty distribution	Achieved

Variables - Ideal Mix of Faculty, Staff, and Graduate Assistants:

x_1 = number of graduate research assistants (GRA)	=	39
x_2 = number of graduate teaching assistants (TA)	=	4
x_3 = number of full-time instructors (INS)	=	2
x_4 = number of "all-but-dissertation" faculty (ABD)	=	8
x_5 = number of assistant professors without terminal degree	=	0
x_6 = number of associate professors without terminal degree	=	0
x_7 = number of part-time instructors without terminal degree	=	0
x_8 = number of staff	=	21
x_9 = number of assistant professors with terminal degree	=	35
x_{10} = number of associate professors with terminal degree	=	21
x_{11} = number of full professors with terminal degree	=	12
x_{12} = number of part-time instructors with terminal degree	=	0
Ideal total of faculty, staff, and graduate assistants:	=	142

Results - First Run-Continued

TP = total payroll budget for the fiscal year	$ 816,000.00
Total expenditures for salary budget in order to attain ideal mix of faculty, staff, and graduate assistants	$1,664,115.00
Budget overrun	$ (848,115.00)

The school salary budget would have to be doubled in order to maintain the ideal mix and to achieve all goals. Although the ideal personnel mix is desirable, limitation of available funds may make goal achievement impossible.

Results of Computer Run 2

The following priorities were assigned to the goals for the second run:

a. Accreditation standards must be met.

b. The desired faculty-to-staff ratio must be achieved.

c. The desired faculty-to-research assistant ratio must be maintained.

d. Operating within the mix of faculty, staff, and graduate assistants on hand, the student demand in credit hours must be met as closely as possible.

e. Desired faculty distribution must be maintained as much as possible.

In the results of the second computer run, the solutions were the results of rounding-off of the previous continuous solutions.

Results - Second Run

Goals		Results
a.	Accreditation	Achieved
b.	Faculty/Staff ratio	Achieved
c.	Faculty/Graduate Research Assistants ratio	Achieved
d.	Faculty/Student ratios	Not Achieved
e.	Faculty distribution	Not Achieved

Variables - Mix of Faculty, Staff, and Graduate Assistants

x_1	= number of graduate research assistants (GRA)	= 23
x_2	= number of graduate teaching assistants (TA)	= 0
x_3	= number of full-time instructors (INS)	= 15
x_4	= number of "all-but-dissertation" faculty (ABD)	= 0
x_5	= number of assistant professors without terminal degree	= 0
x_6	= number of associate professors without terminal degree	= 0
x_7	= number of part-time instructors without terminal degree	= 0
x_8	= number of staff	= 13
x_9	= number of assistant professors with terminal degree	= 31
x_{10}	= number of associate professors with terminal degree	= 0
x_{11}	= number of full professors with terminal degree	= 0
x_{12}	= number of part-time instructors with terminal degree	= 15
Total of faculty, staff, and graduate assistants		= 97

Results - Second Run-Continued

TP = total payroll budget for the fiscal year	$816,000.00
R = total payroll increase from prior budget year	$ 41,016.00
Total faculty, staff, and graduate assistants raises	$ 41,016.00
Total faculty, staff, and graduate assistants raises scheduled in increase budget	$ 16,000.00
Overrun in raise budget	$(25,016.00)

In the second computer run the goals in the first three levels of priority structure were achieved. Student demand was not met with the resulting size of faculty. Faculty distribution goals were also not met. The school was short by 143 credit hours of meeting the student demand at the undergraduate level, and was short by 62 credit hours at the graduate level. The actual faculty-to-student ratio was 1:30 at the undergraduate level (the desired ratio was set at 1:14) and 1:15 at the graduate level (the desired ratio was set at 1:8).

Results of Computer Run 3

In the third and final run, the levels of priorities were assigned to the goals as follows:

a. Accreditation standards must be met.

b. The desired faculty-to-staff ratio must be achieved.

c. The desired faculty-to-graduate research assistant ratio must be maintained.

Third Run-Continued

d. Desired faculty distribution must be maintained as much as possible.

e. Desired faculty-to-student ratio must be met as closely as possible.

Results - Third Run

Goals	Results
a. Accreditation	Achieved
b. Faculty/Staff ratio	Achieved
c. Faculty/Graduate Research Assistants ratio	Achieved
d. Faculty distribution	Achieved
e. Faculty/Student ratio	Not Achieved

Variables - Mix of Faculty, Staff, and Graduate Assistants

x_1	= number of graduate research assistants (GRA)	= 20
x_2	= number of graduate teaching assistants (TA)	= 0
x_3	= number of full-time instructors (INS)	= 2
x_4	= number of "all-but-dissertation" faculty (ABD)	= 4
x_5	= number of assistant professors without terminal degree	= 0
x_6	= number of associate professors without terminal degree	= 0
x_7	= number of part-time instructors without terminal degree	= 2
x_8	= number of staff	= 11
x_9	= number of assistant professors with terminal degree	= 16
	Subtotal carried forward	= 55

Results - Third Run-Continued

Subtotals brought forward from the preceding page	= 55
x_{10} = number of associate professors with terminal degree	= 10
x_{11} = number of full professors with terminal degree	= 6
x_{12} = number of part-time instructors with terminal degree	= 0
The grand total of faculty, staff, and graduate assistants	= 71

TP = total payroll budget for the fiscal year	$816,000.00
R = total payroll increase from prior budget year	$ 43,956.00
Total faculty, staff, and graduate assistants raises	$ 43,956.00
Total faculty, staff, and graduate assistants raises scheduled in increase budget	$ 16,000.00
Overrun in raise budget	$(27,956.00)

The goals pertaining to accreditation standards, faculty-to-staff ratio, faculty-to-graduate research assistants ratios, and the distribution of faculty were fully satisfied and achieved. The only goal not achieved was the faculty-to-student ratios. In fact, the school was more critically short of meeting student demand in Run 3 than in Run 2. The actual faculty-to-student ratios climbed to 1:55 at the undergraduate level and to 1:19 at the graduate level.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

This study investigated the evolution of the university as an organization, from its earliest beginning as an informal structure involving only a scholar and a student, to the heterogeneous, complex organization of today. Literature has been reviewed on the history of the general systems theory, the functioning and types of systems and subsystems, and the development of models to fill a specific need or solve a particular problem.

A resource management model, a single-period linear goal-programming model similar to that of Lee and Clayton (1972), but with a multi-objective non-Archimedean structure used in connection with the computer program MPSX and a prepackaged linear program, SIMPLEX, was developed by the researcher in an effort to provide a means for more optimal planning of budget and faculty mix within one school of a medium-size urban university.

Various constraints on the operations of the school were formulated by the administration, indicating the total monetary budget and the existing faculty and staff personnel. In addition, various goals, ranked in order of importance, were designated by the administration of the school.

In the model, thirteen variables, eighteen parameters, and seven constraints were used to generate the most satisficing strategy; that is, the most satisfactory faculty mix under the given circumstances. By giving the seven constraints (goals) different levels of priority over a series of three computer runs, the researcher was able to determine how much an ideal faculty and staff mix would cost, provided there were no budget limitations, and provided the intention was to meet the student demand in credit hours.

Under the present budget constraints, the study revealed that the school is performing in about as efficient a manner as possible, considering the present faculty and staff mix, and the student demand in credit hours. The model has performed well, and should provide the administration of the school with a valid means for future planning and decision making.

Goal-programming models are not constructed to replace administrators. On the contrary, such models can be of great aid to the administrators in formulating various goal structures, if the school or university does not already have one or more, or in studying the effects of change in their presently existing goal structures.

Conclusions

The model utilized for this study requires that the administrators be capable of defining, quantifying, and ordering objectives. This requirement may be the most serious shortcoming faced by administrators. University administrators and faculty must be certain they are ready for the planning process that requires careful measurement of various objectives that some have considered nonquantifiable heretofore.

For example, what would be the outcome if university dollars allocated to hire new faculty were spent on a competitive basis? That is, the department with the highest level of student demand in credit hours would be awarded the next few positions so that the faculty-to-student ratio in the department or school would be brought to the desired level. It is possible that the administration's strategies would actually call for the discharge of faculty from those departments or schools where student demand levels are low, and consequently, where faculty-to-student demand ratio falls below the desired level.

Would such a strategy imply that one school or department is more important than the other? If this reasoning were applied campus-wide, some schools or departments would vanish in favor of some of the so-called "professional" schools or departments that cater to the career needs of students as well as to their general educational needs.

Such consequences, however, are not desirable if the administration is to maintain a "university environment." The distribution of the limited number of dollars in the university budget, however, needs to be resolved. This is where goal-programming models can be applied and through which reasonable solutions can be identified.

Recommendations

The model presented in this study was a single-period model. More effective, dynamic, multiperiod models must be formulated. The motivation for the development of such models must come from willing university administrators to consider the use of these types of models in their planning activities.

To improve success in implementation, the systems approach should be used to study the decision process, related information problems, and the structure of the organization to determine how models and techniques could be used to achieve the administration's goal of optimal planning in a higher education subsystem.

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