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THE EDUCATIONAL INSTITUTION AS A SYSTEM--A PROPOSED GENERALIZED PROCEDURE FOR ANALYSIS.

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DESCRIPTORS- *SYSTEMS ANALYSIS, *HIGHER EDUCATION, *INSTITUTIONS, *CURRICULUM, INTERGROUP RELATIONS, ADMINISTRATIVE POLICY, INFORMATION SYSTEMS, *EDUCATIONAL IMPROVEMENT, CHARTS, EDUCATIONAL RESEARCH, MODELS, FACULTY, STUDENTS, COMPUTERS, DECISION MAKING,

A UNIFIED APPROACH TO THE ANALYSIS AND SYNTHESIS OF THE FUNCTIONS AND OPERATIONS IN EDUCATIONAL INSTITUTIONS IS PRESENTED. SYSTEMS ANALYSIS TECHNIQUES USED IN OTHER AREAS SUCH AS CRAFT, PERT, CERBS, AND OPERATIONS RESEARCH ARE SUGGESTED AS POTENTIALLY ADAPTABLE FOR USE IN HIGHER EDUCATION. THE MAJOR OBJECTIVE OF A SCHOOL IS TO ALLOCATE AVAILABLE RESOURCES IN SUCH A WAY AS TO MAXIMIZE THE DIFFERENCE IN POTENTIAL BETWEEN ENTERING AND LEAVING STUDENTS. THIS OBJECTIVE IS USED IN DEVELOPING SUCH GENERALIZED SYSTEMS AS CURRICULUM. TWO ORIENTATIONS ARE USED IN GENERALIZED SYSTEMS--(1) CONTROL VOLUME ANALYSIS (ANALYSIS OF THE INPUTS AND OUTPUTS TO AND FROM A FIXED VOLUME OF SPACE) AND (2) CONTROL MASS ANALYSIS (FOLLOWING THE PROGRESS OF A PARTICULAR STUDENT THROUGH THE EDUCATIONAL INSTITUTION). CHOICE OF ORIENTATION DEPENDS UPON THE TYPE OF STUDENT UNDER STUDY, THE LEVEL OF AGGREGATION, AND THE QUESTIONS TO BE ANSWERED. THIS SYSTEMS APPROACH IMPLIES--(1) THE INTRASYSTEM RELATIONSHIPS AND THE INTERRELATIONSHIPS BETWEEN THE SYSTEM AND ITS ENVIRONMENT ARE POTENTIALLY MANAGEABLE, UNDERSTANDABLE, AND CONTROLLABLE, (2) THE UNIVERSITY CAN EVALUATE THE EFFECT OF PARTICULAR PROPOSALS UPON EVERYTHING ELSE THAT TAKES PLACE IN THE UNIVERSITY, (3) ADMINISTRATIVE OR FACULTY DECISIONS CAN BE TESTED QUICKLY AND EFFICIENTLY, (4) AREAS IN NEED OF RESEARCH CAN BE IDENTIFIED, (5) SUBSYSTEMS CAN BE READILY HANDLED, (6) EXISTING AND EXPANDING SYSTEMS CAN BE REDESIGNED, (7) DISCIPLINARY BOUNDARIES TEND TO BREAK DOWN, AND COMMUNICATION TENDS TO INCREASE, AND (8) AN ADAPTIVE MECHANISM IS PROVIDED WHICH MOVES THE REAL SYSTEM TOWARDS IMPROVEMENT. (HW)

# "THE EDUCATIONAL INSTITUTION AS A SYSTEM: A PROPOSED GENERALIZED PROCEDURE FOR ANALYSIS."

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# INTRODUCTION

Systems analysis has been used extensively in many areas. It has been used in the design of machines, electric circuits, defense and weapons systems, communications, industrial management, international relations, and in very recent years in the management of educational institutions. The underlying assumption has been that a school is a system which is potentially susceptible of analysis, design, and perhaps eventually some optimization. This assumption has led to increasing application of engineering techniques relating inputs and outputs, computer programming, simulation vehicles, control and decision theory, and many other tools to the solution of administrative and teaching problems in education. This paper discusses a unified approach to the analysis and synthesis of the functions and operations of schools of higher learning.

SUMMARY OF PAST AND CURRENT WORK IN THE APPLICATION OF SYSTEMS ANALYSIS TO EDUCATIONAL INSTITUTIONS

During the past few years the System Development Corporation has been developing a set of simulation models for five different types of high schools. The objective has been to develop a general simulation vehicle that will permit a designer to construct, on a computer, a detailed dynamic model of real or proposed high school organizations. (1)

A bibliography, which deals with such diverse data processing subjects as optimal scheduling of students, college registration, self-instructional devices in counselling, construction of school simulation vehicles, administration of an automated school, computer simulation of human thinking, and sources of information on educational media is available. (2)

A considerable amount of work in the development of an engineering curriculum has been carried on by the Engineering Department at UCLA during the past few years with the aid of a two-million dollar grant from the Ford Foundation. This Educational Development Program (EDP) has produced some meaningful and systematic procedures for determining the content of a curriculum and the amount of time to be devoted to each item which is to be taught. (3)

The time-allocation work of EDP at UCLA has been extended to the time-distribution problem; namely, the optimum sequencing of subject matter presentation in any given curriculum. This research has considered the well-developed theories of learning and forgetting by taking into account the learner, the teaching method, the type of subject matter, reinforcements, and cumulative learning and forgetting times. (4 and 5)

In recent years, a considerable number of special computer programs

for the scheduling of students, facilities, and faculty have been developed.

Some programs currently in operation are:

GASP, Generalized Academic Simulation Programs, MIT.
SSSS, Stanford School Scheduling System, Stanford U.
CLASS, Class Loading & Student Scheduling, IBM.
FDS, Flexible Daily Scheduling, Brookhurst Jr. H.S.

## THE SYSTEMS ANALYSIS APPROACH

The systems analysis approach requires that we view the system under study from the point of view of its inputs from and the outputs to the universe in which it operates and consider the feedback interrelationships along informational channels between the outputs and the inputs. Figure 1; the conceptual model of any system diagramatically integrates the above procedure. Table 1 discusses the various functions and/or attributes of the components in Figure 1 and also the various names used for similar components by writers or investigators in fields outside of education research.

From the aforementioned viewpoint, any system (and in particular socio-economic systems of the type represented by schools) can be thought of, to start with, as a set of black boxes. Into these boxes we feed various kinds of inputs, and we derive various outputs. The inputs can consist of the measurable properties of people, materials, facilities, and information. The same is true for the outputs. The censor controls indicated on Figure 1 act like valves which regulate the flow, and these valves carry out the additional function of measuring the properties of the flow. If the flow happens to be students, it would measure the student's I.Q., his aptitude, his previous grades, future aspirations, and so forth. This information regarding properties is conceptually transmitted to some sort of data processing system which integrates this information in a logical manner commensurate with the objectives of the system. The way in which this information is manipulated is controlled by a set of decision rules. These decision rules may be very highly formalized mathematical rules or equations or extremely informal sets of rules or pro-

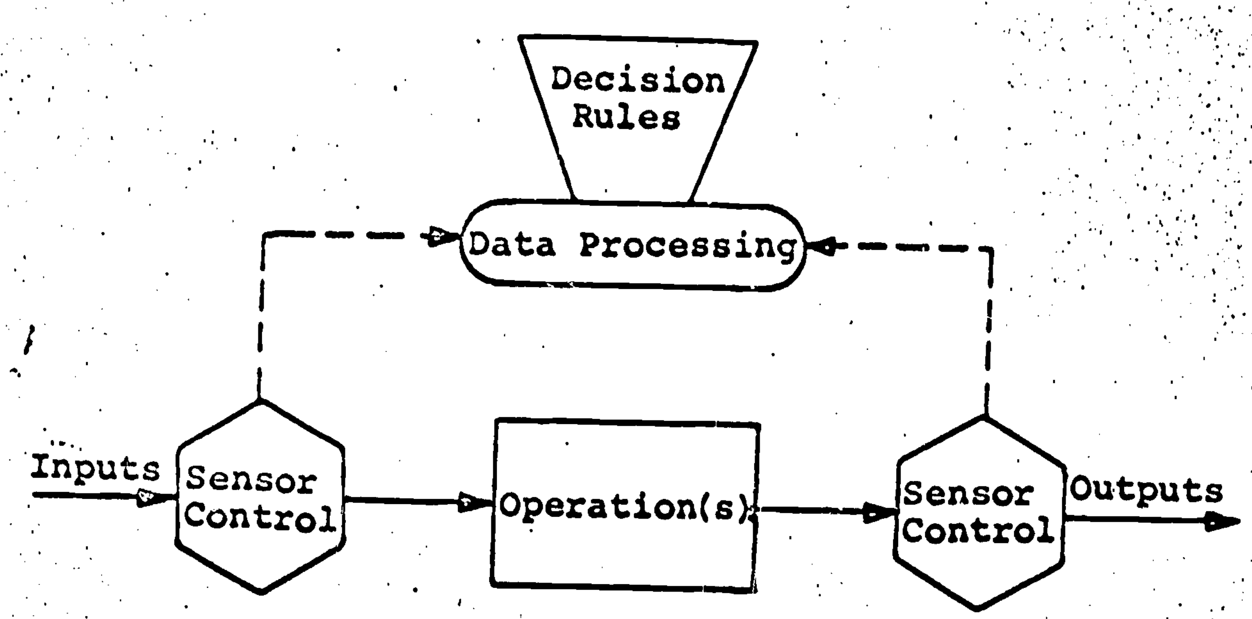



Figure 1.
A conceptual model of any system.

TABLE 1

SYMBOLS, NOMENCLATURE, AND FUNCTIONS OF COMPONENTS OF A SYSTEM

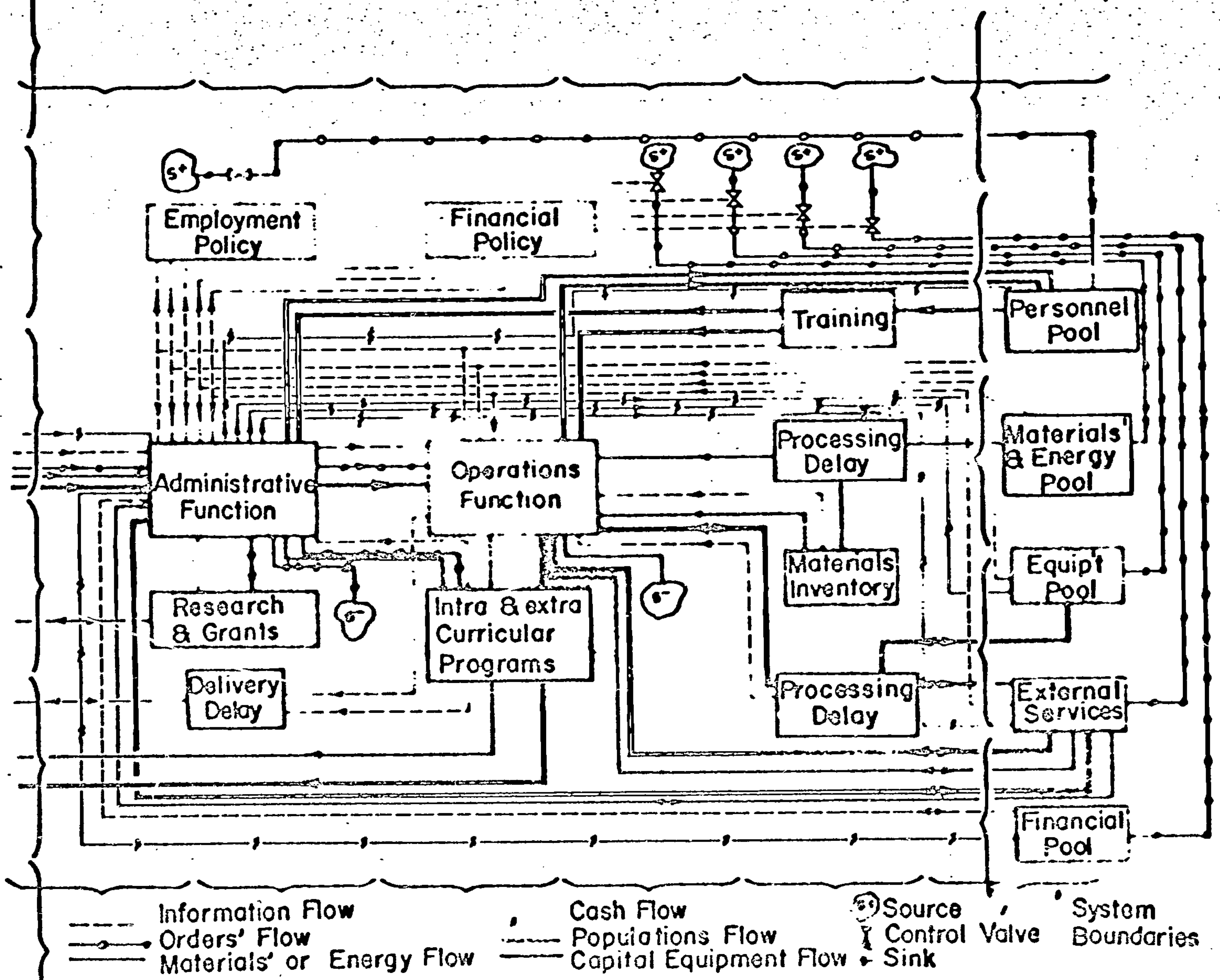
| Component Symbol | Component Nomenclature | Component Functions |
|---|---|---|
| Operation(s) | System thermodynamics Activity (S. D. C.) Level (Forrester) (6) Node (Reisman) (7) Impedance ) Transducer) (electrical) | Obeys the conservation concept for all mass, momentum, and energy flows: Rate of Input + Generation = Output + Accumulation. Examples: Source, sink, storage, any device, school, hospital, department, classroom, library, activity. |
| Sensor Control | Modulator (electrical) Controller (feedback theory) Valve (flow regulation) Instrumentation (property measurement) Transmitter) Receiver ) (info.) | Measures or senses flow properties; transmits property data to data processing; receives control signals from data processing; controls flow rates, splits and directions. Links the mass, momentum, and energy flows with information flows. |
| Data Processing | Information processing system | Performs the following functions on information: Arranging, balancing, checking, coding, comparing, computing, converting, copying, counting, document writing, duplicating, filing, listing, posting, printing, proving, punching, reading, searching, selecting, sorting, summarizing. |
| Decision Rules | Controllers Management Administration Decision functions Control equations Policy | Provides rules, procedures, equations, algorithms, policies, and methods which relate the states (as represented by properties) in various parts of the system to each other and to the surroundings or environment. |

cedures such as those by which people make decisions. In any event, considerable research has been done on decision rules. The rules control how the valves will operate to regulate flow-rates into and out of the system.

Any system must be considered in relation to the environment in which it is imbedded, and the feedback between the system, and the environment is what governs the rates of change which occur inside the system. Hopefully, these rates of change are positive types in the sense that the system and the people inside it are constantly improving upon the procedures that have gone by them in the past.

Applying the above concept to educational establishments, we turn to a generalized conceptual model for socio-economic systems (7, 8). However, the model mentioned has been somewhat revised, and it focuses specifically on educational establishments.

In Figure 2, therefore, we see the boundaries of the educational system having various subsystems such as operations, extracurricular programs, personnel training, and so forth. Outside of the system boundary are various subsystems with which the educational institution communicates either via channels of information or via actual channels through which physical flows (such as flows of people, materials, or energy) may take place. The external subsystems may consist of the student pool, financial pool, equipment or materials pool, and any number of others. Reference (7) has also provided a mathematical vehicle with which some of the flows may in fact be simulated on a computer. In addition to the mathematical vehicle described in above reference, there are other vehicles available. In particular, the Systems Development Corporation has developed a general simulation vehicle that permits a designer of an educational establishment




THE GENERAL MODEL SCHEMATIC Fig. 2

to construct on a computer a detailed dynamic model of real or proposed high school organizations. This vehicle is a simulation and list-processing system consisting of a comprehensive set of procedures wholly in the JOVIAL language developed from SIMPAC. Additional mathematical approaches and/or simulation have been outlined in reference (9).

The basic schematic diagram for a university, however, requires that Figure 2 be deaggregated in order for it to be useful in answering some specific questions which may be posed in a simulation. References (7 and 8) outline one form the deaggregation process may take. However, for the specific case of an educational institution, another approach to deaggregation has been found to be more useful. Before we can procede with deaggregation, however, we must first look at the various major areas of personnel flows and interaction in a school of higher learning. Figure 3 conceptually outlines the various operational areas of the various groups operating in a school of higher learning, and it shows the major areas of overlap and interaction.

Thus, we notice the center core of Figure 3 as the area in which central administration has sole responsibility. Surrounding the area of responsibility of the central administration is the area of faculty affairs responsibility, and the two, of course, show an overlap; and, therefore, mutual interaction. Next, radially we proceed to instructional activities, a major function of the college, and here we again find overlap with faculty affairs as well as those of central administration. Next, we find auxiliary services overlapping with the functions preceding them, and we go on to campus operations. It is interesting to note that if the total system boundary had been drawn further out, there would be an obvious overlapping of the functions of campus operations with those of related services in the surroundings. Thus, the delineation of a boundary represents an arbitrary

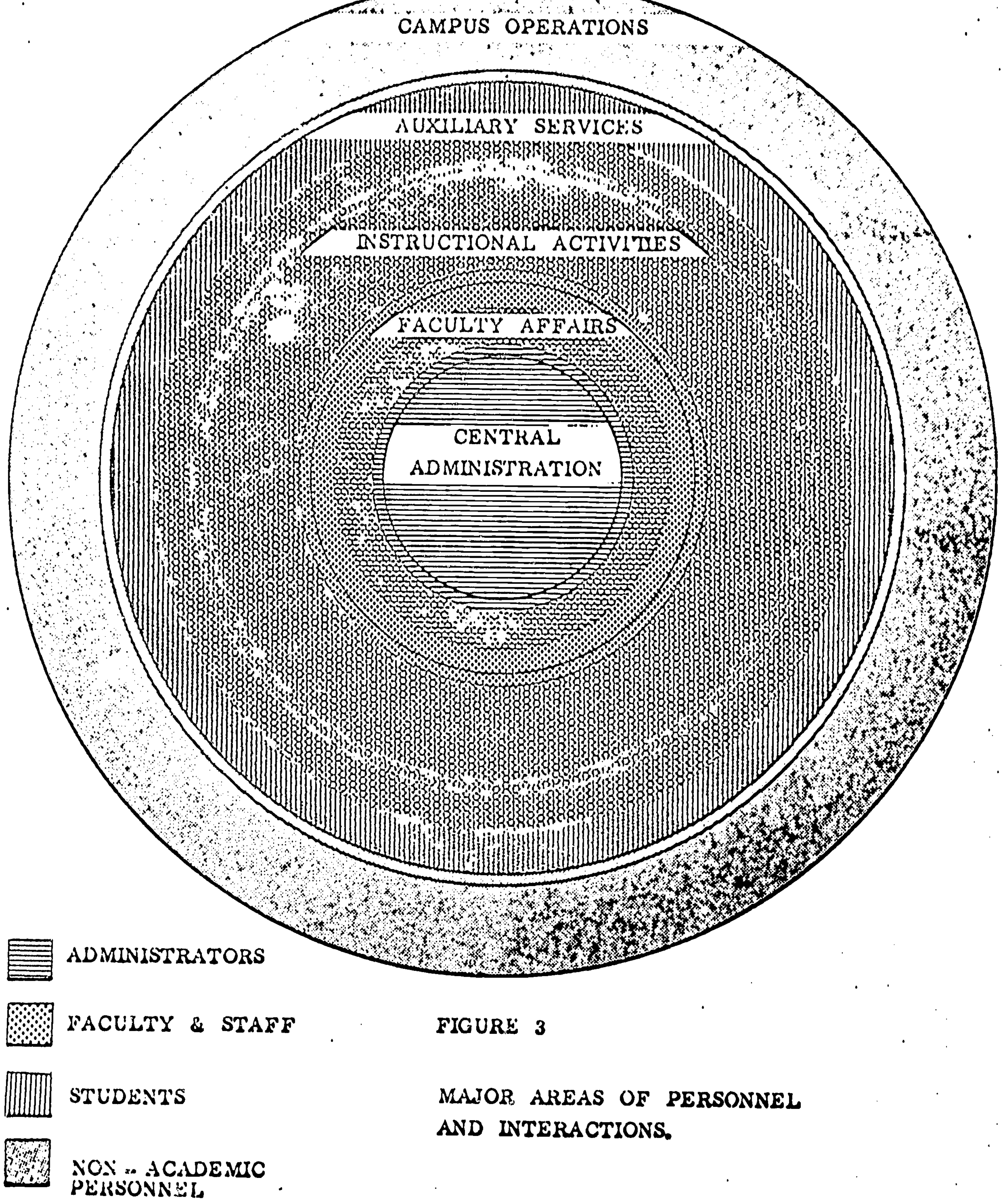



FIGURE 3

MAJOR AREAS OF PERSONNEL AND INTERACTIONS.

choice which is concentrated upon those areas of greatest immediate interest.

Each of these functional areas can now be broken down into more detailed functions. The manner of breakdown will, of course, vary from school to school, but the items indicated on Figure 4 represent what may be found in a typical college or university. Thus, central administration would be concerned with such items as policy making, standards, curriculum planning, institutional studies, instructional services, general budgeting and public relations. The faculty affairs area would include such items as an academic senate, the faculty club, research and grants, publications, and faculty committees. It can be seen that central planning interacts very strongly with faculty affairs in terms of personnel and function. The instructional activity area can be conceptually broken down into such items as schools, departments, courses, laboratory development, work study program, extension program, research supervision, special projects, and advisement. It is in this area that the major functions of most colleges and universities are carried out, and the personnel that operate in these areas, namely the faculty and the students, are in very close interaction, and their actions overlap into faculty affairs and also into the area known as auxiliary services. The activities of the instructional affairs area are supplemented by auxiliary services such as the library, computer center, language laboratory, audiovisual aids, job placement, student activities, bookstores, student health services, guidance, testing, etc. And, finally, in support of all of the activities within the school are the campus operations. Included in the area of campus operations are such items as campus security, publicity, purchasing, accounting, payroll, personnel department, admissions and records, alumni activities, and buildings and grounds.

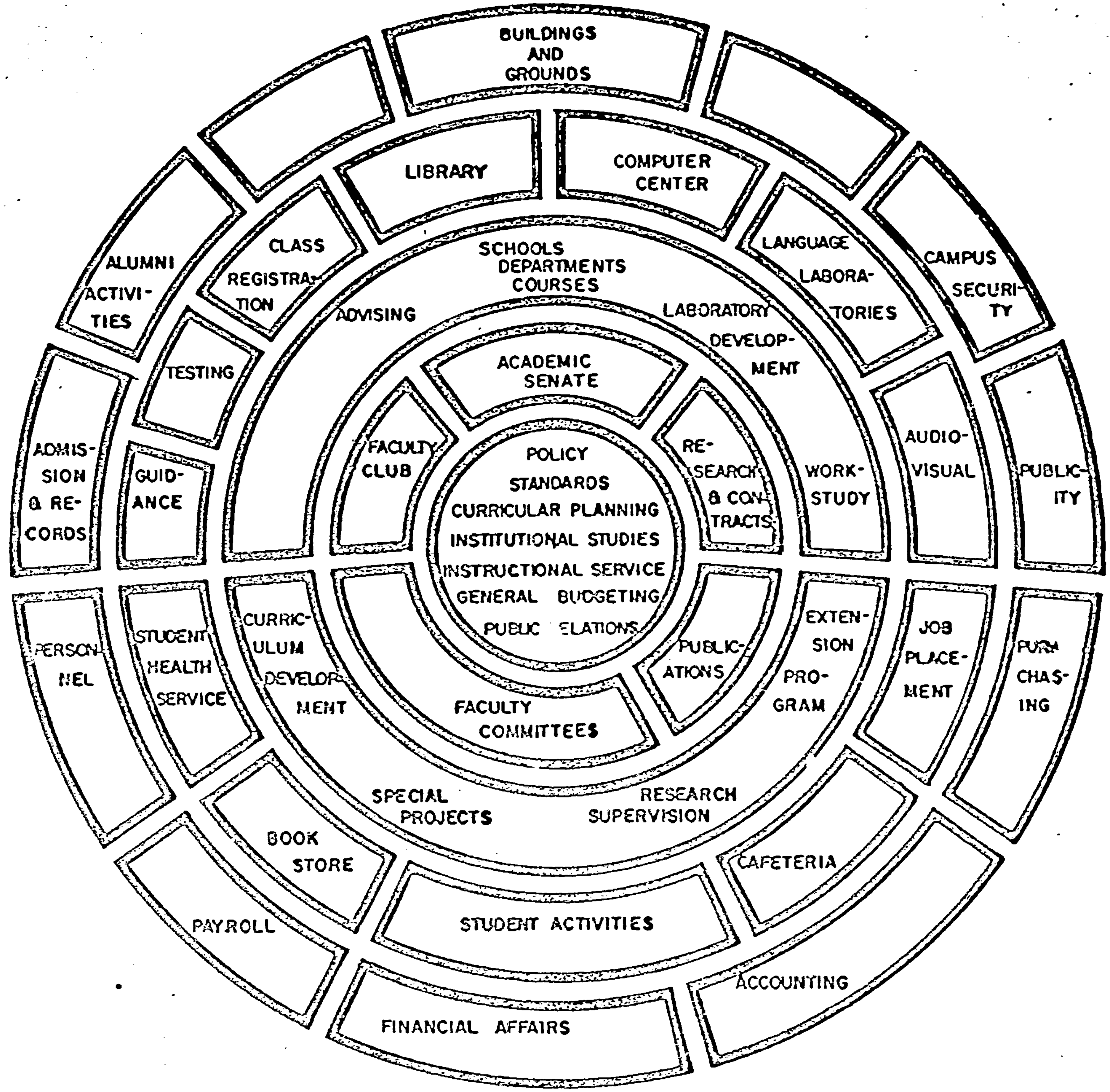



Figure 4. MAJOR AREAS OF RESPONSIBILITY IN A COLLEGE.

It is clear that each of the boxes represented on Figure 4 can and does represent by itself a subsystem of the entire system. Each of the subsystems interacts with all of the other subsystems. This implies that energy, people, materials, and information flows interconnect each box with every other box in the total system. It would be extremely difficult to draw all of the lines of flow, and for this reason, a conceptual way of keeping track of the various flow quantities has been developed. It will be noticed that between each of the major areas or functions of the school, there are corridors, and if we can imagine that each one of the corridors represent the locus of points of travel of any of the major items that are of importance in a school system, we find that our ideas about control of such a system become greatly simplified. In Figure 5 this idea is developed more fully.

If, in the course of an investigation, it is desired to follow the flow of students entering or leaving a school system, it is clear that a student would proceed during most of his time in school, along the corridor between the instructional activities and the auxiliary services. It is in this area and on both sides of it that we would expect to find students. Thus, a student can enter an educational institution and proceed to a guidance department, and then leave a guidance department and enter the testing department, and then leave testing and go to class registration, and from there cross the corridor and enter any one of the schools or departments and from there proceed to a library, etc. At any instant of time the student population may be found on the track inside the corridor or in any of the boxes on either side of it: If we impose sensor controls at the entrances and exits of every one of the boxes of areas of activity, it is clear that we can measure the student's properties both

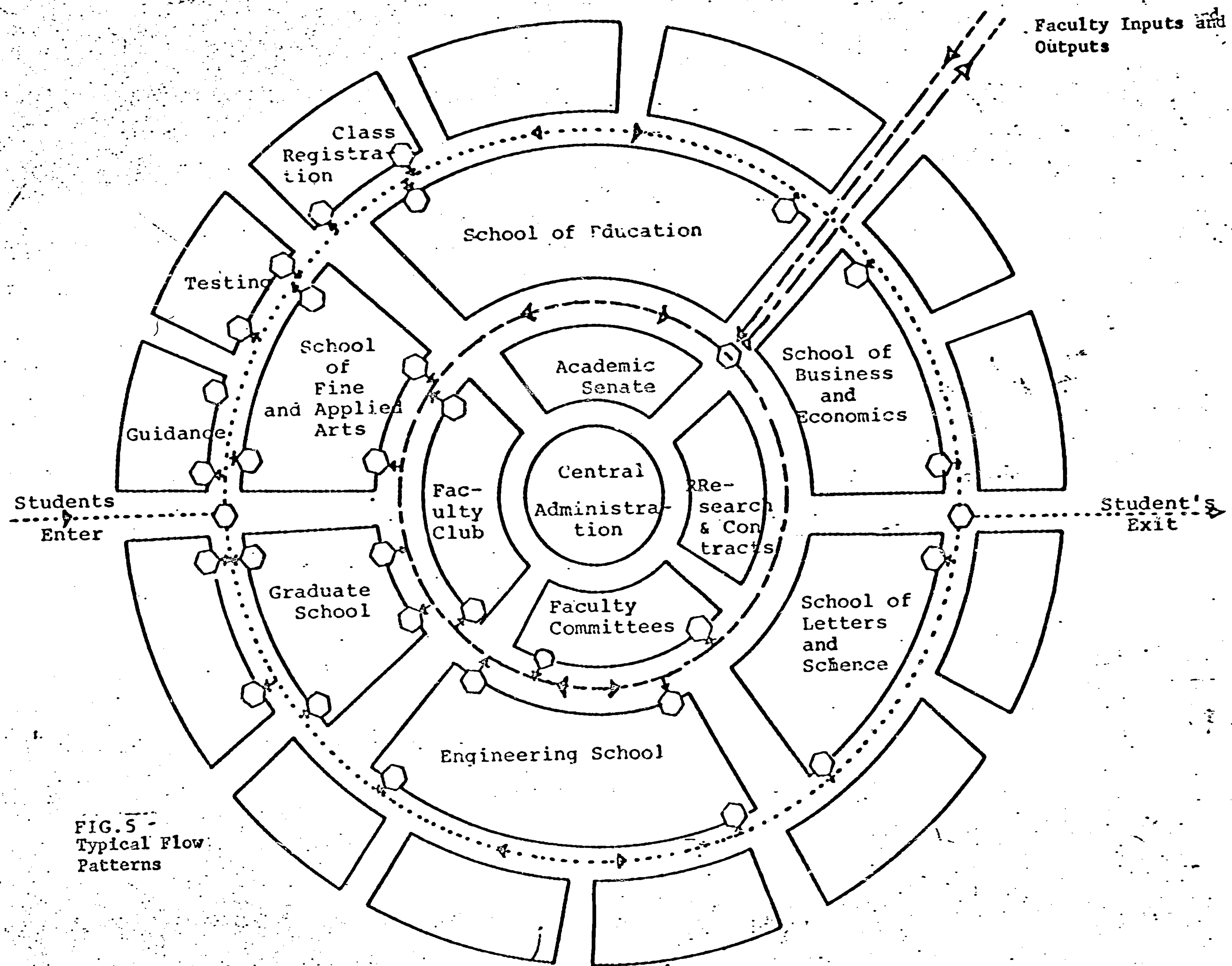



FIG.5 - Typical Flow Patterns

entering and leaving the system and thus have very precise control of flow rates and activities.

In a similar manner, if the center of interest lies with the faculty, it can be seen the faculty would usually be found in the next corridor between the instructional activities and the faculty affairs. Similarly, central administration people would be found in the innermost corridor, and clerical and other auxiliary personnel might be found in the outermost corridor in the diagram. It is not only conceivable but a usual thing in practice to find that some people serve a number of functions. A faculty member may also be a member of the central administration, or may also participate in auxiliary services of one sort or another. But, at any instant of time, each individual is carrying out a specific function or set of operations. If a person is attending classes, then he is a student. If he is at the same time serving in the capacity of a programmer, then he becomes part of the statistics related to auxiliary services, or auxiliary-service personnel. It is not very helpful to consider a person simultaneously in all of the capacities that he may engage in at one time or another. Usually, the mathematical equations for describing flow rates and properties will give systematic descriptions of a given quantity provided that such a quantity is not ambiguous.

Once the flow through the system has been conceptually delineated (i.e. a flow chart has been made of how each type of quantity such as population, energy, materials, and information flow from one point in the system to another), it is possible to apply the concept of conservation. The conservation concept is essentially an elaborate, analytical bookkeeping system for keeping track of various quantities that enter and leave a system or a subsystem (10). The mathematical equations for doing this are highly

developed and have been applied in many areas outside the field of education. The analytical formulations are also susceptible to implementation on large, digital computers with various compilor languages such as MIMIC, DYNAMO, etc. At the present time, the size or complexity of the systems studied is virtually unlimited in terms of the capability of the computers available.

It should be recognized that although simulation languages and programs have been developed for application to industrial and socio-economic systems, few if any languages or programs have been developed for educational institutions. A notable exception, of course, is the high school simulation vehicle developed by the Systems Development Corporation (1). This vehicle is a simulation and list-processing system consisting of a comprehensive set of procedures, wholly in the JOVIAL language developed from SIMPAC. It is constructed in modular form so that models can be built up by assembling the modular parts (activities, procedures, packages, modules, and total systems) into a particular configuration. An extensive series of flow charts delineate all school functions operationnally. Individual or batch flows can be accommodated by what amounts to an elaborate bookkeeping system.

The major flow parameters in a school are similar to those in companies or industrial establishments, but there are some significant differences, and these require a considerable amount of additional research before they become tractable.

## A CONCEPTUAL APPROACH TO SYSTEMS ANALYSIS RESEARCH IN HIGHER EDUCATION

In the preceding sections, some of the tools for systems analysis in education were indicated. These tools may be applied to any combination of basic problems of interest in educational institutions.

The search for a unified way of thinking about research problems in education has lead to the development of the schematic representation shown in Figure 6. This diagram was designed to make it possible to systematically explore the various areas of research in education. Figure 6 is basically a more detailed version of Figure 1. It specifies the major inputs to the basic components of a school system.

The operations of an educational institution are determined by its educational objectives. From a managerial standpoint, the major objective of a school is to allocate available resources in such a way that the difference in educational potential between entering and leaving students is maximized. Students enter a school system with a given level of educational potential and, hopefully, leave with a much higher level. The central task of administrators is to allocate faculty, staff, material, facilities, and information at such times and places and in such proportions that the objectives of the school will be achieved in a most efficient manner.

The school which is shown in the diagram as a black box represents a highly complex socio-economic system. Students are the major input (raw material) of the system. Alumni, school dropouts, and transfer students are the output (product). Other inputs to the school are the faculty and staff, materials, orders (purchasing), facilities, and information. The exchange of information between the system and the environment is not shown on the diagram for the sake of clarity but it does exist. It is this exchange of information with the society in which the school is imbedded

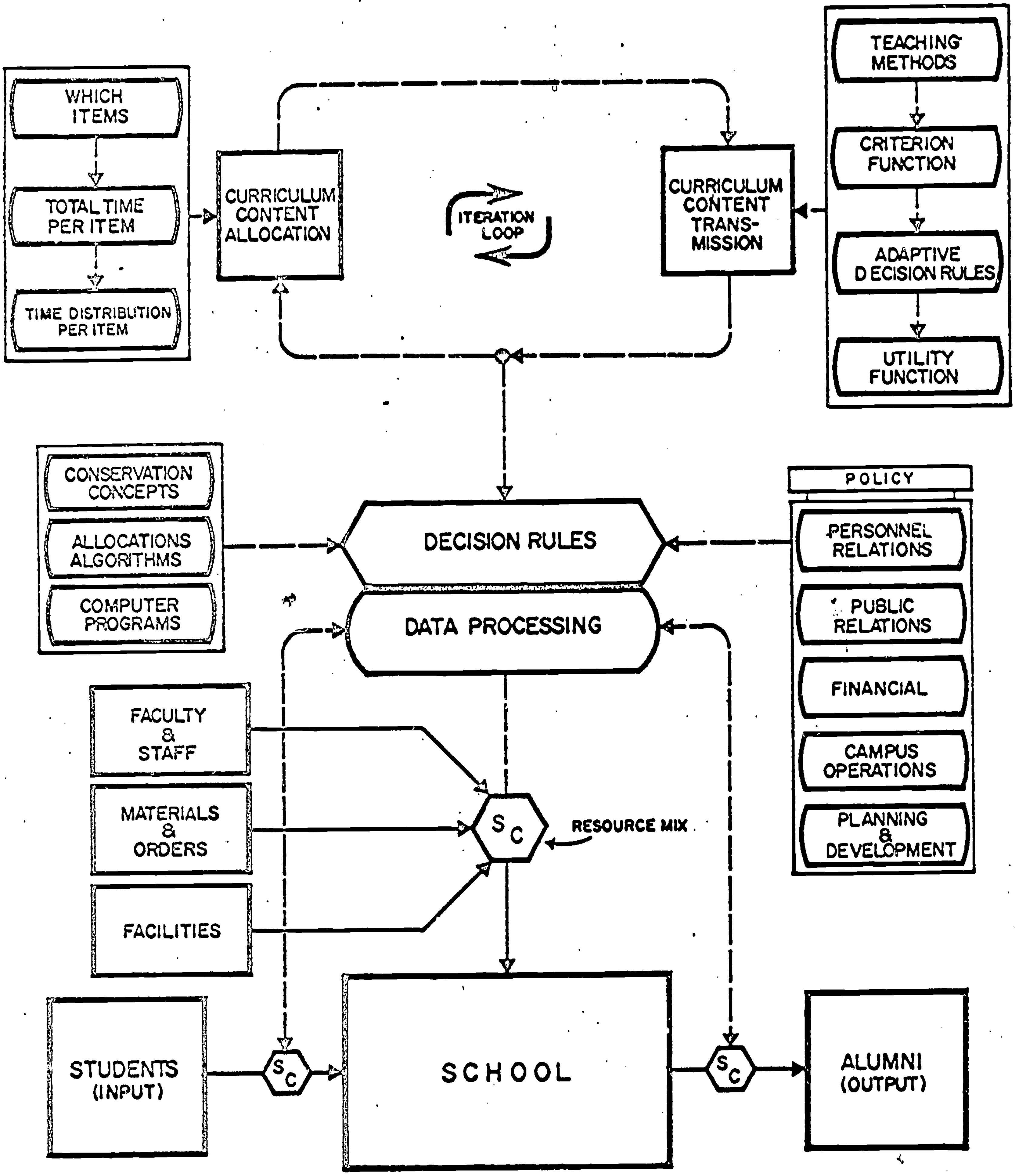



Figure 6. A SCHEMATIC REPRESENTATION FOR SYSTEMS ANALYSIS RESEARCH

that makes the operations of the system meaningful. The larger systems that surround the school provide general educational objectives, curriculum constraints, limitations on funds, and other important inputs. The properties of all the inputs and outputs are constantly monitored by the sensor-controls.

The sensor-controls not only regulate the flows into and out of the system but also measure the properties, convert them into signals that are sent to the data-processing system and receive new signals which in turn determine new flow rates. The way in which the data is processed is determined by a large number of decision rules. These decision rules are, in the case of a school, determined by the faculty and school administrators.

As can be seen from Figure 6, the decision rules in an educational institution are derived from three major sources: the rules that are expressed explicitly by mathematical formulations, the administrative policies and procedures that are usually known to the faculty and staff in an implicit or verbal manner, and the curriculum. The explicit decision rules governing educational institutions are not as yet fully developed. The interrelationships between the various subsystems of a large social system like a school can be described mathematically by the application of the conservation concepts; namely, the laws of conservation of mass, momentum, and energy.

The authors in reference 10 have shown that when these conservation laws are formulated in general mathematical equations the basic equations for many fields can be derived from them as special cases. An examination of the basic equations (the Navier-Strokes equations) has shown that they are directly applicable in such diverse areas of physical science as aerodynamics, solid mechanics, thermodynamics, strength of materials, fluid

mechanics, statics, dynamics, heat transfer and electric circuits. Using an expanded form of Kirkhoff's laws for electric circuits, one of the authors 7, 8 has developed a mathematical framework which consists of K node or junction equations, M potential or branch equations, N constraint or auxiliary equations, and a methodology for their application. These equations provide for nonlinear and transient behavior of any socio-economic system as well as physical system and give recognition to the value of system simulation techniques.

Although these equations offer useful descriptions of the flow of such diverse quantities as materials, money, energy, people, and information, they incur numerous practical problems in connection with the storage, retrieval, listing and processing of the myriad of data or information generated in a school. Additional research is needed to determine the units of measurement for information; to discern, measure, and control "impedances" and "potential differences" in a school system; to develop techniques for handling mixed and coupled flows at a node; to generalize the equations to include mutual inductance; and to develop rational procedures for converting information which is now available regarding schools into a form that can be used in the model.

The development of allocation algorithms, particularly those concerned with the allocation of funds and facilities has been a highly decentralized process in the United States. Although a substantial number of allocation methodologies have been in use by government and industry in recent years, few of these have been adopted by colleges and universities. Some techniques that have great potential usefulness for the growing and expanding educational institutions are:

1. CRAFT, Computerized Relative Allocation of Facilities

Technique, could enable college administrators to quickly and economically evaluate many possible school facilities layouts. This technique could help to determine the optimum location on a campus of the library, the cafeteria, the computer center, and the administrative offices (11)

2. PERT (12) and other critical-path techniques could be used in the planning and controlling of the work force and financial requirements of large school construction projects.
3. CERBS, a general financial model, reduces to their present worth all disbursements and receipts involved in the possession and operation of capabilities to perform services and/or produce goods. (13) This model could be used in colleges to systematically compare and evaluate a variety of policy decisions concerned with the purchase and replacement of laboratory equipment maintenance tools, office and computer equipment, and large capital outlays.
4. Operations Research, which has been utilized with increasing success in problems related to community health services, could be applied in higher education for facilities utilization studies; economics of automating library, registration, and student health services; statistical patterns of demand for college courses; and for the development of models to describe real-system behavior. (14)

In contrast with the lack of integrated basic research in the areas of decision-making described above, a large amount of work has been carried on in the areas of educational data processing of student records and the scheduling of students into classes. Through cooperative efforts between industrial organizations such as IBM and educational institutions like Stanford University and Massachusetts Institute of Technology, a number of comprehensive computer programs have been developed and made operational. These computer programs are being used to supply data of all kinds at any time; to rapidly and efficiently carry on the multitude of activities related to school registration procedures, record keeping, grade reporting, and budget forecasting; and to produce master schedules for assigning courses, faculty, facilities and students.

Another large class of inputs to the decision rules of an educational institution consists of the administrative policies of the school. These are policies related to such items as personnel relations, public relations, finances, campus maintenance and operations, planning and development. These policies vary from school to school, department to department, administrator to administrator. Often, policies are formalized in faculty handbooks, administrative codes and committee minutes; but usually, they are contained in the minds of the people who are doing the work. As yet, few formalized procedures have been developed for systematically and economically gathering and compiling policy information so that it can be readily used in systems analyses and computer simulation of the educational system. The most significant input to the decision rules in an educational system, however, is the curriculum.

## THE CURRICULUM: A MAJOR INPUT TO DECISION -MAKING

The curriculum, educational program, or program of study reflects the purposes and educational objectives of the school. It delineates the ways in which the student population is to be transformed while passing through the educational system. Hence it is concerned with the educational process; what is to be taught, how much, when, where, and how subject matter is to be transmitted. Curriculum synthesis implications constitute primary inputs to the decision rules which control the data processing and ultimately the operations of the entire educational system. Decisions regarding the allocation of faculty, staff, facilities, equipment, and services flow directly from a knowledge of the requirements of the curriculum.

In order to consider some of the research that recently has been carried on in the area of curriculum, this area will be divided conceptually into two parts; the curriculum content allocation and the curriculum content transmission. These two parts form an iterative loop as shown in Figure 6. Studies are made to determine what and when subject matter should be taught, then the teaching methods are studied, then original assumptions regarding time allocations to the subject matter are re-examined and revised, then the teaching methods are improved, and so forth. At any instant in time, the data regarding the current status of our knowledge of the curriculum can be tapped off from the iterative loop and supplied to the decision-making component of the system.

A comprehensive review of the literature on curriculum planning and development during the period of time between June 1960 and June 1963 is presented in the Review of Educational Research (15). Most of the

literature reviewed was written by persons who are engaged in the research in education, psychology, and related fields. The following section will indicate some of the recent research in the area of curriculum which has been conducted by persons with mathematical and/or engineering orientations.

Curriculum Content Transmission and Allocation

The emphasis in curriculum content transmission has shifted in recent years from research on conventional teaching methods, through programmed textbooks and simple mechanical teaching machines, to computer-based instruction. John E. Coulson, at System Development Corporation, has pointed out that a few controlled experiments with computer-based teaching systems, while encouraging, have not yet demonstrated clear-cut superiority of this method of instruction over simpler, more orthodox teaching methods. (16) In addition to research and development of learning laboratories, special mechanical teaching and communication devices, and time-sharing computer systems, programmed learning has lead to basic research in learning theory.

A considerable amount of attention has been focused upon optimum methods of presenting instructional items to the student. (17) Programmed instruction has dealt largely with linear (fixed sequence) programs, and with branching programs (scramble books) which offer the student alternative paths or item sequences through the lesson (18). James E. Matheson, at Stanford University, (19) has studied the teaching of a list of paired-associate items in a fixed number of presentations. He assumed the validity of the simple learning model of Atkinson and Estes (20), formulated a reward structure in order to measure the effectiveness of teaching, and in terms of the reward structure and the learning model he derived optimum teaching procedures by applying dynamic programming techniques to Markov

processes. It is usually assumed that the state of the Markov process is directly observable at each step in the process. It is then possible to base all decisions about the process upon the state of the Markov process without regard to the past history of the process. But the state of the Markov learning model is not directly observable and those observations that are available depend upon the state of the model in a probabilistic manner. Matheson derived an equivalent Markov process in the observable states of history and then treated this new process by conventional means in order to optimize it.

In his engineering doctoral dissertation, Arnold Roe (21) developed an analytical adaptive decision structure for educational systems. His decision structure rested upon four cornerstones: a plan for gathering and using data; an explicit criterion function; a set of decision rules for achieving the criterion; and a utility function which relates system inputs and system outputs to a value scale outside of the system. The utility function defines the output of an educational system as the increment in life-cycle productive output attributable to the educational experience for all individuals who have been part of the system. It provides a means for converting such available measures as student grades, student learning time, teacher inputs, school capital and maintenance costs, and so forth into a net value of the transformation effected by the system. The suggested criterion function which must be maximized is the sum of the net utility of all students' outputs. Roe also developed decision rules which tend to maximize the criterion function under different conditions of á priori information. This research leads to the development of a computational backwards-induction solution for the multi-stage or continuous sampling procedure from normal populations.

The objective here is not to discuss the merits, assumptions, or

implications of the foregoing research but rather, to indicate the type and scope of recent research efforts in the field of education by people who have mathematical and systems-analytic orientations. The two references just cited contain extensive bibliographies of other recent research projects in this field.

The curriculum content allocation problem has been studied ik-tensively by the Engineering Department at UCLA during the past few years. The Educational Development Program has produced some meaningful and systematic procedures for determining the content of the curriculum and the amount of time that is to be devoted to each item to be taught. The proposed procedure for curricular synthesis involves the application of three criteria to the subject matter of the curriculum. The amount of time allocated to each instructional item, topic, or course depends upon its relevance to the aims of the curriculum (the criterion of relevance); the degree to which an item helps or reinforces other items (the criterion of generality); and to a lesser degree, the use that a given item makes of other subjects (the criterion of articulation). This procedure maximizes the relevance of the whole curriculum to the aims of engineering design. The procedure can be generalized to fields other than engineering by defining different categories of subject matter and by adding other criteria as deemed necessary. (3)

This procedure, which has also been utilized in curriculum synthesis studies at the School of Engineering at Dartmouth College, provides a systematic and relatively objective methodology for determining which items should be taught and how much time to spend on each item. It does not directly consider the problem of how to distribute the presentation of each item in time, i.e. when should each item be taught.

The problem of when to teach an instructional item or more generally, the problem of optimum scheduling of subject matter, was studied by one of the authors in his Ph.D dissertation (4). It was shown that the integration of basic principles of learning and forgetting, derived from educational psychology, leads to the concept that the degree to which a student has mastered a course, topic, or item in a curriculum is a function of the type of subject matter, the type of learner, the teaching method, and the sequencing and type-distribution of the subject matter. A mathematical model which facilitates the construction of optimal and suboptimal schedules of subject matter was developed. The model is intended to be used to estimate the degree of student mastery of one or more subjects at the end of the course of study. It takes into account logical and time constraints such as prerequisites and maximum hours of classwork allowable per week. A heuristic solution technique requiring the use of a large digital computer yields an improved schedule for a given body of subject matter and a known time allocation for each item. A large digital computer program for implementing the scheduling model was developed and made operational.

Validation and refinement of the sequencing model will help to bridge the gap between curriculum theory and its practical implementation in the classroom. In the final analysis, the success of a given educational program hinges upon the ability of the faculty and administration of a school to schedule each student into sequences of courses which will maximize the student's educational potential on the day of graduation, minimize the rate of forgetting after graduation, and achieve the educational objectives of the school.

In the foregoing sections, some of the areas of research having high payoff potential were considered. The implementation of these relatively

new and untested concepts requires a rather systematic set of procedures for integrating these methodologies into a conceptual whole.

The next section is addressed to the exposition of such procedures.

## A GENERALIZED SYSTEMS ANALYSIS PROCEDURE

The value of the schematic diagrams and conceptual models developed thus far lie in the ability to translate these ideas into practical applications. The practical application can only be determined when we consider the analyst's vantage point in the system. From a given vantage point, specific kinds of questions may be asked. Those questions related to students, to central administration, and to the faculty. In addition, these can be extended into areas of economics, public relations, and a host of others. For the purpose of this paper, only two or three specific problems will be handled and a number of specific procedures for implementing the model will be presented or outlined.

### Alternate Analysis Perspectives

Depending upon the type of system under study, the level of aggregation selected, and the questions to be answered, one of two possible types of orientations may be selected in the analysis. The first orientation will be entitled Control Volume Analysis, and the other orientation we shall label Control Mass Analysis.[1]

The Control Volume approach is concerned with analysis of the inputs and outputs to and from a fixed volume of space. The space could be anything such as a classroom or a university or a high school. The inputs and the outputs to such a system may be students or drop-outs and alumni respectively. In addition, any socio-economic system will have other inputs as well as outputs. These could be inputs of materials such as educational materials, audiovisual aids, and so forth. It could have inputs of energy; electrical

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1 The above names are borrowed from the engineering jargon, specifically from such fields as Thermodynamics or Fluid Mechanics.

energy, heat, etc. It could have inputs of information; that is, information from the outside world regarding the kind of curriculum that the world requires, the kind of students that the world supplies, the kind of alumni that the system is expected to put out to the world. The world also communicates with the control volume through the fact that it supplies faculty and other supporting personnel as well as money for the operation of the program.

The Control Mass approach, on the other hand, is concerned with the observer following the progress of a particular student going through the educational institution. It may also consider the flow through the system of a particular item of materials or a particular amount of energy. Although the physical sciences use either one or the other of the above approaches, in the field of socio-economic systems it has been found helpful to apply both approaches in the analysis of any one particular system. Thus, we first view this school as a highly aggregated unit operating in the world through which the various flows of students, faculty, money, energy, materials, etc. take place. However, we soon find out that the measurement problem in the socio-economic systems is much more grave or difficult of attainment than it is in the physical world. Thus, in order to get significant measurements on the status of operations in the institution, we must focus on some particular flow going through this system. Thus, we are faced with the necessity of having to turn to the Control Mass Analysis point of view. Another way of viewing the Control Mass approach is to consider the system analyst as sitting on top of a flow item, such as a student, and watching all of the inputs and the outputs and the transformations which take place as the item or student moves through the system.

This type of approach permits consideration of how the environment impinges upon the students. Thus, it is found that they are subjected to

information flows, they carry out certain activities, they expend a certain amount of energy, and so forth. Hopefully, in the problem under consideration, the activities that the students carry on increase their educational potential. We now ask the same question as before: Can we look at an individual student or group of students as a system and measure a sufficient number of properties so that we can decide whether the objective function is being optimized or achieved. Towards this end, various achievement and attitude tests may be applied at different points in time while the student is in the educational system.

## THE SYSTEMS DESIGN PROCEDURE

Figure 7 represents a highly aggregated schematic of the iterative processes involved in the design or redesign of socio-economic systems. This design procedure is an outgrowth of well-established methodologies in the engineering design of complex physical systems. Moreover, it is an extension of the work performed by the System Development Corporation (1) in the simulation of schools at the secondary level and of the design procedures involved in the Educational Development Program, U.C.L.A. (22)

The starting point of the design sequence may occur at any stage of the iterative loop. If the system must be designed in its entirety, then the starting point may be as shown in Figure 7. However, in the modification or in the redesign of an existing system, it is possible to start at any other point in the loop. Thus, if a simulation model exists and has been validated by field testing, then one might start at Step 17 in the diagram.

Many flow diagrams similar to Figure 7 can be found in the literature. While the meaning of most of the steps in the diagram is self-evident, some elaboration may be desirable for clarification. Hence, the following section.

In defining the objective functions of the system (Step 3), we could consider a major educational objective of the school, which in this case is the maximization of the student's educational potential between the time he enters and the time he leaves. Or for some other problem such as analyzing the financial department of a college, the objective function might be to minimize the operating expenses of the institution. The problem of defining the objective functions is a very difficult one, especially at the beginning of an analysis. This is often due to the fact that all of the

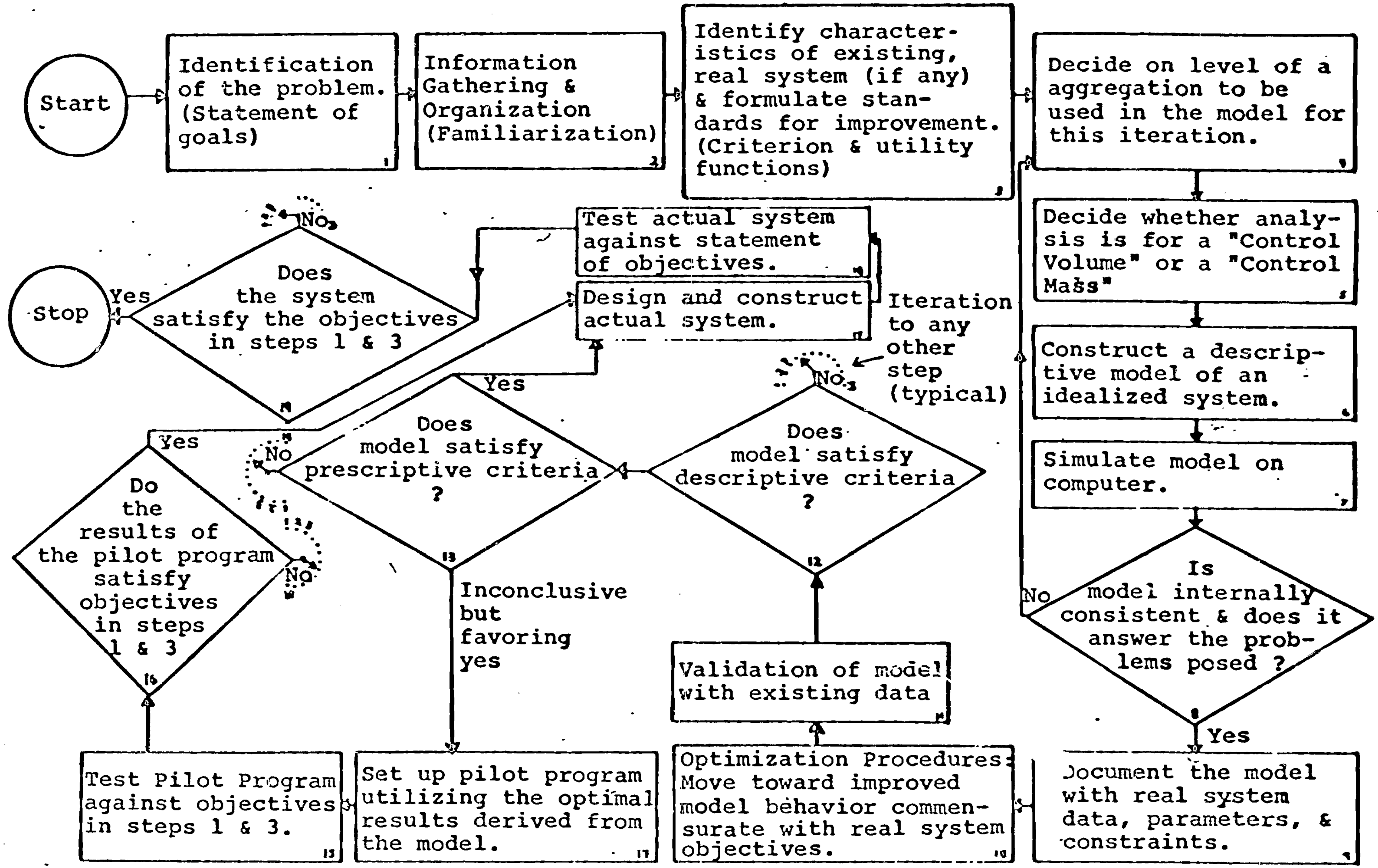


Fig.7. Generalized Systems Design Procedure:

A Schematic Representation of the Iterative Process.

pertinent information is not available. However, tentative generalizations can be made and ultimately be refined as the analysis proceeds. In general, there is more than one objective function to be either minimized, maximized or forced in a desired direction. The usual attempt is to find one single major objective and optimize it subject to a series of lesser constraints.

The descriptive model of the system usually consists of a series of generalized block and flow diagrams (Step 6). The block diagrams delineate the control volumes that will be used in the analysis. Each control volume usually represents a subsystem of the entire system, in this case the entire system is a school and subsystems may be a library, classrooms, departments, purchasing, and all the other kinds of operational entities within a school.

The control volumes usually represent highly aggregated levels of the system. This implies that many of the activities are lumped together into a larger subsystem, and when we deaggregate, we break down into finer and finer levels, smaller and smaller subsystems. Into each of these control volumes or subsystems there will flow mass (which could be people, materials, and all of the other quantities mentioned earlier) and some of these quantities are stored inside the control volumes and some of them leave. The conservation laws are applicable in this case in a straightforward manner. This has been well documented and developed (7, 8, 23). Figure 2 consists of a series of operations blocks in which we look at individual quantities as they pass through the various subsystems. Thus, if the quantity in question is a student, then we would look at the flow of students into an admissions office in a school, entering a testing area, counseling, registration, classes, etc., and we trace the entire time history of the

student in the school system. The flow diagram delineates all of these things, and shows their interrelationship. Once we reach a point in which we can see the total picture in terms of control volumes and we have an initial concept of all the interrelationships, then we ask whether we can measure the properties of the various flows in such a way that we can determine whether the system is achieving its objectives. For the case in question, we consider measurability of sufficient properties (usually properties of the students) so that we can determine whether we are maximizing their educational potential in passing through the system. At this high level of aggregation, the chances are that we will not be able to measure the quantities which are necessary for the kind of analysis outlined. Therefore, we switch to a Control Mass Analysis. We observe all of the interactions of a single student or a group of students with the environment. From a theoretical standpoint, the answers that we get from this Control Mass Analysis should be identical to those from a Control Volume Analysis. However, the difference in perspective gives us a great deal more information and ability to measure things. Ability, for instance, to measure the student's I.Q. or ability to measure student's test scores in various courses, or a student's financial ability. After looking at the student from this perspective again, we can measure the various properties of the flow? And if we find that the measurements which can be made are sufficient to enable us to set up standards for achieving the objective functions, then we would proceed to the next step in the systems analysis. If not, we return to our Control Volume Analysis and deaggregate. The deaggregation process involves breaking down into more and more elemental components each of the subsystems that have already been delineated. As an example, if we are concerned with the measurement of the student's educational

potential. Therefore, we deaggregate and break each of those subsystems into a finer set. Thus, a given school might be broken down into departments, and still further, each department into individual courses through which the student passes. This process of deaggregation of systems into subsystems and the interrelationships between subsystems has been schematically as well as mathematically developed and discussed in references 7 and 8. By looking at the student's flow through individual courses, we find that we are at a level of aggregation where we can measure the student's properties. Perhaps it would be better to use the words "state of knowledge" of a student as opposed to the word properties. When a student enters a course, we can measure his current state of knowledge, and we can also measure his new state of knowledge as a result of passing through the given course. This concept is analogous to measurement of the state of physical substances as they pass through a system. Any particular state of being is a function of or can be described by several properties. The properties of educational potential may be:

1. Ability of the student to play back information he has gained.

2. His ability to apply the knowledge gained to new situations (i.e. analysis and/or synthesis).

3. His ability to extrapolate the information to other fields and to new situations.

4. Development of attitudes and approaches to various problems; a way of thinking.

5. Problem-solving.

Having reached a level of aggregation at which the variables in question could not only be quantified but also measured, we are now in the position to develop a mathematical or a computer-based model of the system.

We next program this model on a computer and simulate the output (that is the behavior of this system) for different kinds of inputs (Step 7).

If our outputs are sufficiently good (that is, they are close to the objectives we have set out for ourselves and for the system) then we need not bother any more. We have a well-designed and operating model. However, it is more likely that the outputs will deviate quite a bit from the system objectives. We are now at a branching point (Step 8) where we have to make a decision as to whether we should relax our objectives or whether we should redesign this system so that it would approximate the objectives more closely. Thus, having the computer as a laboratory of sorts, we can alter various arrangements within the model, change various parameters, or alter the so-called transformation functions of some of the subsystems, (that is, the ways the systems operate on the flows going through them). And by doing this, we hope to bring the outputs closer to the objectives we have set for ourselves. In addition, through the medium of simulation, we can test for the extent or the ranges of the various parameters within the system. Furthermore, we can test for the sensitivity of the model to small changes of parameters or transformations within the model. Thus, we can isolate those variables and those parameters which are most crucial to the operation of the real system to the extent that the model represents reality. Once having isolated the sensitive areas of this complex, dynamic model, we have identified those parameters which need further testing to get more exact data. These are the parameters which will give us a high payoff for the effort expended in quantifying them more precisely. For those parameters and/or variables to which the system is relatively insensitive, no testing is necessary. A good approximation for such variables will suffice. Furthermore, the parameters and/or variables which show a low level of influence on the dynamic behavior of the system can be aggregated or lumped together thus reducing the number of variables and/or parameters that we

need to work with on the computer.

It is an established fact that the human mind, although operating on a much higher level than the computer, is limited as to the number of variables that it can manipulate logically. The interrelationship of variables in a system of the type we are talking about is often dynamic; that is, it is time-dependent, it is non-linear, and complex. Furthermore, within the system as Figure 2 indicates, there are so-called feedback loops. This means that information emanating at the output of a subsystem may be used as an input to the same subsystem, thus, regulating the subsystem in question. Furthermore, the output of a school of higher learning (the alumni) may be at times used as an input to the faculty of the school. This again creates certain feedback phenomena which could be either stable or unstable. An example of undesirable though stable feedback is represented by the problems inherent in the "imbreeding" of faculties.

After the simulation of the model on a computer, it is necessary to utilize these results in looking once again at the entire system. The procedure that can be followed is to reaggregate from this low level to a higher level. Thus, if the simulation has taken place on systems such as classrooms or at the level of courses, these are aggregated at the level of departments and the departments are aggregated to the level of divisions and schools, and then ultimately to the entire school. As we aggregate to each one of these new levels we consider the result of the simulation and consider whether the previous way in which all of these subsystems were interrelated are reasonable and logical and whether the functioning and operations of these subsystems are consistent with the objectives set forth at the outset. It will probably be found that some changes would need to be made in the various systems and their subsystems. As these changes are made, it is a continuous iterative loop, which develops until there is a

reasonable level of confidence that the model does in fact reflect the real system. It is at this point that we consider documentation of the actual system that we have in mind (Step 9) or getting information (specific information) regarding the actual school or the actual classroom that we are studying.

The next step (that is, the step following a situation when we have arrived at a working model) is the step requiring that we compare the model in its various subsystems and interrelationships to the reality. If we find that the model approximates our conception of reality to a fair degree, we then proceed to test it in the sense that we test a model in a laboratory. We test our computer simulation for various ranges of parameters. At this point, it should be clearly realized that we will never get an exact statement or an exact model of the actual operation of a system in real life. We must, therefore, be satisfied with no more nor less than the consensus of opinion of professionals in the field as to their conception of the operation of the various subsystems and their interrelationships with each other and their effect on the whole.

Once the model has been established and some data has been obtained from the actual system through field testing, we can now go back and iterate to any previous step of the design procedure and improve the procedure on the basis of this new information. Thus, we have a feedback loop in carrying out our system analysis. As our knowledge is improved regarding both the field system and the model, both hopefully do or can be improved, and we move closer and closer to the original objectives set forth for this system (Step 10). However, these objectives do not necessarily have to remain stagnant. They too can evolve as we learn more and more about the model and reality.

The literature of mathematics, management science, operations research,

and industrial engineering is replete with well-established methods for system optimization and for model validation. The scope of this paper does not warrant further elaboration.

## CONCLUDING REMARKS

Some of the implications of the foregoing systems approach are:

1. The dynamic and the static interrelationships between subsystems, variables, and interrelationships between the system and its environment are potentially managable, understandable, and controllable. Thus, as an example, we can site the facc that a faculty member developing a new course can prejudge the effect of his contribution to the entire curriculum and to the operations of the entire school, including the problems which it may develop in relation to faculty, facilities, students, and so forth.
2. The university can evaluate the effect of particular proposals, whether they be for a course, or a laboratory or a policy, in relation to everything else which takes place in the university.
3. The simulation provides a vehicle through which various decisions of the administration or of the faculty can be tested quickly and without undesirable consequences, such as high costs, lowering of of educational standards, and poor public relations.
4. The simulation allows for identification of areas which require more field testing and which can provide a "high payoff" in terms of the overall objectives of the school. Thus, a host of high payoff areas for research and development can be identified and progress can be made in an organized way.
5. Because the systems are so complex in reality, we can now operate on the various subsystems as well as on the entire system introducing a variety of recently developed tools available in such

areas as operational research, industrial engineering, management science, cybernetics, mathematics, etc.

6. A model of this sort can be used to either redesign existing and/or expanding systems to improve operations or for the design of entirely new systems of education.

7. One of the major problems of administrators in higher education is the problem of disciplinary boundaries (that is, the boundaries which have been established around various departments, disciplines, and so on). A systems approach to the analysis of educational institutions tends to break down these boundaries and to bring together people who would otherwise not communicate with each other regarding matters of common interest. In other words, this tends to break down what is referred to as Academic Chauvenism.

8. Previous studies have shown that the initiation of any systematic investigation of the dynamics of a socio-economic system has the immediate and often desirable effect of inducing changes which would not ordinarily have taken place. However, the design procedure discussed in this paper includes an iterative loop and thus provides an adaptive mechanism which moves the real system towards improvement.

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