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ABSTRACT

A 2-phase project has been undertaken to develop a research and development planning system which consists of (1) a systematic procedure to formulate research projects, and (2) a systematic procedure to guide the selection of a subset of projects. Phase 1 of the project involves the development of a meta model which is based on a modular concept and assists in building models of educational systems. Information gathering projects are needed to load the model, and a project selection model is proposed which helps select a subset of projects designed to maximize available resources. Phase 2 of the project deals with field-testing the procedures in order to determine their generalizability. The Center for Occupational Education at the North Carolina State University will serve as the testing site, and the following activities are planned: (1) Performance criteria of the Center in terms of its mission, goals, and objectives will be delimited, (2) A specific approach for generating projects in accordance with the goals will be developed, and (3) The project selection procedure will be exemplified with illustrations. (SB)

# DEVELOPMENT OF A PLANNING SYSTEM FOR EDUCATIONAL RESEARCH AND DEVELOPMENT CENTERS

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# PREFACE

During the last several decades, the systems approach to management decision-making has grown increasingly important to many different types of institutions. The systems approach has been of importance in industry for the development and selection of new products, and in research for the development of new items in technology, including as perhaps its most prestigious product the successful mission of landing men on the moon. As our sophistication in the use of this approach grows, we are moving more and more toward its use in situations less clearly defined than simply the cost of developing a new product and the estimated return from its sale.

This paper represents an attempt to carry the systems approach into the very complex world of educational research and development. Here, decisions based on costs and returns are much more difficult to make. The factors influencing any project selection decision in educational research and development are primarily judgmental, and biases in judgment can have a very great effect on not only the development and selection of a project, but also on its actual outcome. Yet, even though there are innumerable difficulties in the application of systems management techniques to educational research and development, it is worthwhile to begin work on the adaptation of this approach. The demand on current financial resources for educational research and development is already high and the prospects are such that competition for the research dollar will get even stiffer. The development of sound management techniques for the educational research and development enterprise could go a long way toward maximizing the effects of our scarce resources.

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John K. Coster
Director

SUMMARY

A Research and Development planning system for educational R & D use is developed in this study. The general R & D planning system consists of (1) a systematic procedure to formulate research projects and (2) a systematic procedure to guide in selecting a subset of projects.

The development of a meta model based on the General Purpose Simulation System (GPSS) language dictates the procedure to formulate projects. The meta model based on a modular concept is a plan which assists investigators in building models. Information-gathering activities needed to load the GPSS model constitute projects. Projects so generated can be so numerous that there would not be available resources necessary to carry out all the projects. Hence, a project selection model is proposed which would select a subset of projects so as to maximize the cumulative expected reward within the available resources.

It is also shown in this study how the general R & D planning system can be oriented to the Center for Occupational Education. After forming guidelines for the generation of projects, the effects of changing variable values on the project selection process are shown using the computerized project selection procedure.

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## INTRODUCTION

The last few decades have witnessed an increased emphasis on research and development activities in almost all sectors of society. While industries have been concerned with the research and development of new products and the improvement of existing ones, government has been concerned with implementing the concept of research and development in public service agencies such as the Department of Defense and the U. S. Office of Education. The result has been an increase of research and development centers and activities in business, industry, and government.

Research and development is regarded as a composite of basic research, applied research, and development. Research can be defined as "systematic intensive study directed toward fuller understanding of scientific knowledge of the subject studied" (Perlman, 1963). Within this general statement one can make subtle distinctions between applied and basic research, principally in terms of motivation and the need for research. Basic research is primarily concerned with achieving "fuller understanding," whereas applied research has a "practical" objective inview; that is, applied research is concerned with exploring the possibilities of applying the knowledge gained through the basic research in product or process development. Development, as a separate activity, can be defined as "the systematic use of scientific knowledge directed toward the production of useful materials, devices, systems, or methods, including design and development of prototypes and processes" (Perlman, 1963).

The main objective in the creation of research and development centers is to produce certain specified results at a particular point in time. Human and physical resources are mixed to obtain specified results. In the research and development process a group of people are engaged over a period of time in a purposeful cooperative endeavor. The plan of action of the research and development process requires making the resources productive. It requires channeling human efforts in the proper direction. This is accomplished by management processes. Management processes integrate the unrelated resources into a system for the accomplishment of objectives. Management also holds the responsibility for converting the provided resources into a valuable product. Management is necessary for the research and development process; it is indispensable for accomplishing the desired objectives.

According to Koontz and O'Donnel (1959), there are five management functions--planning, organizing, staffing, directing, and controlling. These five terms can be described as follows:

Planning. Basically, a decision-making problem which involves choosing among various alternatives. It is the function of selecting appropriate policies, programs, and procedures to meet the desired goals of the organization.

Organizing. After the programs and procedures are selected, activities to achieve the program objectives are determined, groups of activities are formed, and the groups are assigned to departments.

The department heads (managers) are delegated the authority to carry out the assigned activities. Thus organization deals with systematic determination and allocation of activities to the prescribed departments.

Staffing. Staffing is the managerial function that comprises the necessary activities in manning and keeping manned the positions provided for by the organization structure.

Direction. Involves guiding and supervising subordinates.

Control. Basically an evaluative function; serves to compel conformation to plans of action.

Although the five functions are listed and described separately, it should be remembered that they are not independent activities; nor is any exact time sequence implied.

## Educational Research and Development

Educational research and development centers have been established to allow programmatic thrusts directed toward finding solutions to problems.[1] Most of the educational research and development centers are fully or partially dependent upon the government and/or private agencies for their survival and stability. The educational research and development centers supported by the U. S. Office of Education are funded originally for five years, but with the premise that excellence of contributions would likely warrant extensions of the grant for another five years. In other words, if the outcomes of the projects undertaken by a center are not in line with what is expected of the center, namely the mission of the center, the financial grants may not be extended. The demand for program relevance has created many problems for research and development project management.

Almost all research and development centers have experienced difficulties in making decisions on which projects to undertake. Brownell (1968) contends that many educational research and development centers do not possess or do not delineate the bases or procedures for making decisions to determine what projects to undertake. Bloom (1968) attributes this difficulty to the complications in securing a clear focus on the missions, problems, and procedures. The demarcation of an area, for example, has sometimes meant that any problem that falls within the area is related to the mission. If there is considerable diffusion, the purpose of an organization will be diluted and sometimes lost.

[1]Reference is made to the research and development centers established by the U. S. Office of Education under the Cooperative Research Act and Section 4(c) of the Vocational Education Act 7, 1963.

Another problem facing the educational research and development centers is the fact that presently many research works in education are carried out by persons with varied disciplinary backgrounds. The result has been a mix of conclusions which could not be readily matched or intermingled to produce a satisfactory solution to a problem. What is needed are neat arrangements through simplified, orderly presentations of information. This calls for a unified, integrated system suitable for any educational application. The present paper is addressed to the development of such an overall planning system suitable for research and development organizations. Its objective is to present a research and development planning system which offers promise for a programmatic thrust of the research and development activities. In this connection, some of the procedures and practices that are recently being highlighted can demonstrate usefulness for educational research and development centers.

## Systems Philosophy of Management

The five managerial functions--planning, organizing, staffing, directing, and controlling--are simplified when the assigned personnel can focus their attention upon a narrowly defined, explicit task. However, when the tasks become complex where specialization of functions is required, it becomes necessary to integrate the area into an effective whole. For example, a director who is in charge of a multimillion dollar research and development organization (NASA) has a more complex job than a manager whose functions are well defined and explicit. The manager who is in charge of complex managerial functions faces the problems of relevance to stated objectives, the development and choice of clear alternatives, the balance and integration of plans and operating systems--all part of what might be called a "systems philosophy of management."

The systems approach is not a method, a technique, or a set of techniques. It is a concept, or a way of viewing a problem; a way to investigate alternative solutions for complex problems under uncertainty. It is not a technique to solve problems, but rather a means to look at problems in their total context. As such, one cannot expect that the systems approach can solve all problems at all times. This blunt fact is necessary to understand the role of the systems approach properly.

Primarily, the systems concept provides a way of thinking about the job of management. It helps to prepare a framework for visualizing internal and external factors affecting the organization as an integrated whole, and for recognition of the proper role and functions of subsystems. One can think of a system "as an organized or complex whole, an assemblage or combination of things or parts forming a complex or unitary whole" (Kast and Rosenzweig, 1962).

The systems approach helps to view the research and development process as an entity and not simply as a combination of some research and some developmental activities. Research and development is thus considered as a set of interrelated processes for dealing with problems. Coordinated efforts are required in solving the problems. Channeling of the coordinated efforts sets forth a need for competent management within the research and development process itself. A competent research and development management combines the available human and material resources and integrates the research and development activities.

The major functions of research and development management, according to Gilford and Yovits (1965) are: identification and formulation of critical research problems, selection of projects, organizing and directing of personnel to perform research activities, identifying and exploiting promising lines of inquiry, appraising project status and progress, evaluating personnel and output, communicating results, and developing implications for further scientific progress or for technological utilization.

The necessity for an integrated effective whole of activities, arising from the complexity of managerial functions, leads to the concept of systems management. Systems management is primarily a managerial and organizational concept adapting the managerial functions mentioned above to complex interfunctional and interorganizational relationships. The systems management runs under a variety of names, such as Program Management or Program, Planning and Budgeting system (PPBS). Basically, it is the philosophy of the integration of all the activities necessary to the accomplishment of the primary goals and objectives. It is based upon the integrative and coordinative activities of focusing a myriad of functions on the accomplishment of total organizational goals (Kast and Rosenzweig, 1962).

## Systems Approach and R & D Management

The science of project management was so ably applied at NASA, where the successful completion of the mission of landing men on the moon was accomplished within a decade of initiation of the program, that it has become invaluable to other R & D centers, particularly to educational R & D centers which are in their infant stage.

Von Braun (1963) provided a detailed discussion of the organization and management of the Marshall Space Flight Center which was assigned the responsibility of executing the program. The key to success, according to von Braun, has been the creation of a Central Planning Office. The main objectives in establishing this office were "to assist top management by providing consolidated overall planning, closer program coordination, and increased management data and support."

When diversification of projects appeared, the top administrator was faced with the need to bring the management responsibility back into sharp focus, to fuse talents and skills into an easily identifiable pattern and recognizable personality, and to get swift and firm action and considered decisions. The solution to the problem was accomplished using the concept of project management.

Good project management practices start with careful planning. Planning is the construction of an operating program that is comprehensive enough to cover all phases of operation. It must also be detailed enough so that specific attention can be given to its fulfillment in controllable segments. Fundamental planning usually requires the kind of background study that is possible only through full-time effort, painstaking research, and application of specialized skills and techniques (Rosenfield and Smith, 1967). There are basically seven functions of planning in the vast majority of departmental R & D organizations according to Rosenfield and Smith (1967). They are: (1) project selection, (2) project review, (3) liaison and communications, (4) budget preparation, (5) long-range preparation, (6) manpower provision, and (7) organizational analysis.

Project selection refers to initiation of projects. The initiation of projects is the most critical planning responsibility in many R & D organizations. The accelerating cost of research and development places a premium on careful screening of projects to assure the greatest return.

Before the projects are initiated they are reviewed to determine the success probabilities. During this process, various alternative avenues of attaining the project objectives and their relative merits are estimated.

Liaison and communication function of the planning helps to integrate the diversified activities and serves as a source of information on varied research activities.

The annual budget is a plan of action expressed in terms of dollars and manpower. As such the budget is an accounting process which generates estimates of resources required to carry out the projects.

Long-range planning is usually based on forecasted information. It projects the possible future programs and resources (money and manpower) requirements.

Manpower position refers to the process of determining what type of people are needed, in what numbers, and at what cost. The planning is done on both a short-term and a long-term basis.

Organizational analysis is the process used to analyze and evaluate the whole organizational structure to determine if the organizational structure and the people in it produce a compatible system.

For the purposes of this study, the functions of the program management can conveniently be encompassed under three main headings: (1) Planning, (2) Execution, and (3) Review.

Planning consists of (a) specifying the work to be done, (b) generating a set of projects, (c) estimating the cost and manpower requirements for the projects, and (d) developing project selection procedures to optimize the return for resources expended.

Actual project activities are carried out in the execution phase. This includes (a) selection of the personnel to activate the projects, (b) preparation of a project procedural statement by the project director covering technical aspects involved in the execution of the projects, (c) evaluation of the project statement in terms of sound methodology, data collection and analysis, relevance to the specifications, etc., and (d) execution of the project work.

Under project review and evaluation the progress of the project is monitored. The continual flow of information provides the management decision-maker a basis for deciding whether to continue, to modify, or to terminate a project.

## Scope of the Study

Chase (1970) states that the concept of large-scale research and development as a systematic approach to the attainment of educational goals is relatively new, although there has been a recent proliferation of organizations for this purpose. As educational R & D organizations are in their infancy, any attempt to develop management systems is only at a developmental stage. This study represents an attempt to develop the rudiments of a project management system suitable for use in educational R & D centers.

The implementation of a management system at educational R & D centers is assumed to offer promise as a means of integrating the efforts and focusing the impact of these centers on educational innovations. However, the development of a total management system requires extensive commitment of efforts and resources. Consequently, the scope of the present study centers on the first phase of a project management system, namely "planning."

The project is divided into two parts. A set of objectives is specified for each part. Part I is the developmental phase of the project. The attendant objective is to produce a general program planning system.

Part II is the testing phase of the project, and the ensuing objective is to develop a specific procedure that can be adopted at the Center for Occupational Education, North Carolina State University, which will serve as a testing site for the procedures developed in Phase I.

The first set of objectives deals with the development of project planning systems that can be used at the educational R & D centers.

The specific objectives in this phase are:

1. Development of a procedure which can be used to generate projects.

This involves the development of a meta model for building models of educational systems. The development of the meta model will be based on a modular concept that can satisfy the requirements for model building. The modular concept will base on one of the computer simulation languages. The meta model will list questions to be asked in building models and supplying answers to these questions will result in a specific model. The list of ingredients that are necessary to build models will be listed in the meta model.

Answers to the questions, that is, the collection of necessary and required information for model building, will help to formulate projects. The number of projects so formulated may require a greater amount of resources than the available resources. Hence, a procedure will be required to select a subset of projects that will yield optimum payoffs for the available resources.

2. Development of a project selection model that will help to maximize the expected payoffs for the research and development efforts within resources constraints.

Quantitative methods, particularly the operations research techniques, will be explored in developing the selection procedure. Various models in the literature will be examined in terms of endogenous and exogenous variables and associated measurement problems. Feasibility of applying the existing models to the domain of educational research will be studied. If necessary, one or more existing models will be modified to suit the purpose.

The second phase of this study deals with field-testing the procedures developed in the first phase in order to ascertain their generalizability. The Center for Occupational Education at the North Carolina State University will serve as a testing site. The set of objectives in this phase are:

1. Delimiting the performance criteria of the Center in terms of its mission, goals, and objectives.

The director of the Center will be conferred with in specifying the mission, goals, and objectives of the Center. Expert opinions available in the literature will be given due consideration in delineating the mission, goals, and objectives of the Center.

2. Developing a specific approach for generating projects for the Center in accordance with the goal areas.

A schematic representation of the planning system will be presented. The planning system will incorporate the principles developed in the first phase.

3. Exemplifying the project selection procedure with illustrations.

A set of data will be artificially generated to illustrate the project selection procedure. The data will be generated in such a way as to demonstrate the full implication of the project selection model. The project selection procedure will be computerized. A computer program will be written, incorporating the algorithm for solving the project selection model.

## R & D PLANNING SYSTEM FOR EDUCATION

Planning is one of the most important tasks of an R & D manager. Planning is necessary for coordinated activities of a concentrated purpose. Without good planning the purpose may be diluted and sometimes lost. Planning also serves as a vehicle for controlling the activities Any activity that is of useless nature can be detected and eliminated. Necessary activities are identified and carried on. Thus, planning is a vital and integral part of R & D management.

As generally used, the term planning refers to the development of detailed method, formulated beforehand for doing or making something. Hence, a scheme is required to categorize, determine, derive, specify or formulate R & D activities. For our purpose, planning can be defined as the construction of an operating program that is comprehensive enough to cover all phases of R & D activities. A systematic approach to planning recognizes two key schemes: (1) a scheme to identify R & D projects, and (2) a formula to select projects from all identified projects within the resources available.

The R & D process being defined as a system has its mission. Although the mission of the educational R & D process may vary, it is not unreasonable to assume that a plausible mission is to offer innovative changes for better educational processes or educational systems. Incorporating this fundamental assumption, planning of educational R & D should offer promise for a programmatic thrust in solving the problems. The planning system starts with a procedure to systematize the formulation of projects. As the financial resources and other resources are limited, it is also desirable to have a decision-making procedure to select projects. The selection procedure should be such that the cumulative expected return from the selected projects is optimum for the resources expended.

### Generation of Projects

The machinery for generation of the educational R & D projects should be based on what is expected of the educational R & D organizations. Chase (1970) has indicated that the educational R & D organizations were started with a promise "to provide educational agencies with carefully designed and tested products, procedures, and systems appropriate to their goals and function."

In solving problems, educational researchers have relied many times on classical statistical techniques. It is not unsound judgment to rely on statistical techniques when the extraneous variables can be controlled. To this extent, results from the statistical analysis are valid when the extraneous sources of variations are controlled as in laboratory experiments. Controlling the variable many times eliminates interesting and valuable variables from study. This may result in false conclusions which would become evident when the conclusions drawn from the statistical analysis do not conform to actual experience. If the results of the analysis do not conform to actual experience, the investigators often may not know where to turn for evaluation of conditions which determine the success or failure of the solution to problems. Even the skill in sampling techniques and experience in multivariate analysis still restrict the investigators to research designs which have conditions that cannot be approximated as in real settings. In this respect the systems approach is very appealing.

The systems approach helps to view problems in their contexts. The problems and solutions to the problem are always entertained in relation to total situations. All important variables are given due considerations. Possible alternatives for solutions are explored. The problems are analyzed in their total environment. Contrary to the case of statistical analytic tools, the variables can be varied and/or controlled as the situations warrant. This helps the decision-maker to evaluate the various effects of solutions on the total systems. To understand R & D in its perspective as a system one has to understand what can be called "General Systems Theory" (GST).

## General Systems Terminology

A whole which functions as a whole by virtue of the interdependence of its parts is called a system. To restrict it in the realm of scientific thought, Hall and Fagen (1968) define a system as a set of objects together with the relationships between the objects and between their attributes. The definition implies that a system has properties, functions, and purposes distinct from its constituent objects, relationships, and attributes. Objects are simply the parts or components of a system. The objects may be physical such as men, equipment, etc., or abstract such as mathematical variables, rules, and laws, etc. Attributes are properties of objects. For example, stars have properties of temperature, velocity, etc. The relationships are those that "tie the system together." It is, in fact, these relationships that make the notion of a system useful. The method which aims at discovering how this is brought about in the widest variety of systems has been called General Systems Theory.

In applying GST one has to define the system under study. The term system covers a wide range of phenomena. We speak, for example, of philosophical systems, number systems, communication systems, control systems, and educational systems. Some of these are conceptual constructs and others are physical entities. The following three notions of systems are often confused and never are precisely distinguished: (a) conceptual systems, i.e., formulizations in the sense ordinarily employed in mathematics, (b) "real systems," living or non-living, i.e., objects in physical space-time which are observed and measured ordinarily by methods and procedures common to the natural sciences, and (c) abstracted systems, either relationships of various parts or classes of behavior which can be identified in, or exist between "real" systems.

For our purposes, we are interested only in those systems which display activities. Thus we are concerned with "behavioral" systems which are dynamic in time. Behavior is defined in terms of energy exchange within a system or between systems resulting in movements. The essential characteristic of a behavioral (dynamic) system is that it consists of parts, each of which displays behavior. We can further narrow it down to those dynamic systems which are controlled by human beings. Consequently, the solar system, for example, even though it is a behavioral system, is not a part of the subject matter of our system research. Thus, the systems under study are behavioral systems where the human beings are sine qua non.

Again, we are not interested in all systems where the humans are involved. Our concern is only with those systems that offer services to the society--satisfying the needs of the society. Further, we limit ourselves to those systems that are culturally based and maintained to provide differentiated services and/or to perform specialized functions for society, particularly the need for human resource potential development (Miller, 1968). This brings the educational system into sharp focus. The educational system is one that satisfies the above mentioned criteria while eliminating other societal systems such as health care, military systems and such others.

Once the system under study is defined, the next phase is to decide the type of study. There are three terms tagged to the word "system": analysis, evaluation, and development (design or redesign).

## Systems Analysis

Systems analysis yields as accurate a picture as possible of the structure and functions of the system--of the way the system is put together and of the processes that go on in the system. It tells the investigator what the system is about and what it does. The information is obtained following two stages: namely, (1) assessment, and (2) description.

The assessment phase consists of (1) specifying the dimensionality of system outputs, and (2) developing means of measuring system performance. Description provides a detailed accounting of environmental influences and constraints as well as relations between components, resources, and the decision-making powers wherein the performance of each component is incorporated into decisions regulating the performance of the total project complex.

Assessment. To assess what the system is about one should know the performance of the system. System performance has meaning in the context of three mutually dependent terms: mission, goals, and objectives. Mission is the ultimate aim of the system. Mission is conceived in terms of the ultimate purpose of the system which is accomplished in its terminal phase. The system implements this ultimate purpose through a series of preliminary activities performed through time and phases. As such, the mission is achieved through desired outcomes over time and phases. Desired outcomes are the goals of the system. Those functions which assign utility (desirability) to outcomes are termed criterion measures.

System goals are the resultants of system-environment interaction. Each goal is assumed to have measurable units. Accomplishing the criterion level of measurable units of goals produces objectives or system outputs. The outputs react with environmental states to produce desired outcomes.

Objectives are defined as desired states of criterion measures of performance. They are some precise and specific measures of goals. They indicate the system performance in measurable units, or how well the system is progressing toward attaining the goals. Schematically the interrelationships between objectives, goals, and mission are presented in Figure 1.

Description. A system is usually described in terms of its environment, components, resources, and management (Churchman, 1968). Description of the system leads one to understand the internal structure and mechanisms of the system. It actually helps one to comprehend the constitution and compositions of the systems. A system is always viewed in relation to its environment.

Each system may be said to exist within a specific environment. The environment is usually considered as being external to the system, and is defined as a set of all objects, within some specific limit, that may conceivably have bearing upon the operations of the system. The delimiting factor of what constitutes an environment for a particular system depends on which objects are and are not to be considered part of the system. This is no easy matter to determine. In this context it is useful to consider two points of view: (1) Churchman's and (2) von Bertalanffy's.

Following Churchman's (1968) concept, the environment imposes constraints on the system. The system can do relatively little about the behavior of the environment. Environment, in effect, makes up the things and people that are "fixed" or "given" from the system's point of view. The environment assigns parametric values to the system operation and components.

We must keep in mind key words such as Restriction, Boundary, and Constraints. Restrictions are the sum of rules, regulations, and self-imposed or externally-imposed guidelines that bound the system. The concept of boundary prescribes a limitation within which the objects, attributes, and their relationships are adequately explained. Constraints are the conditions that limit and describe how the objectives are to be attained.

According to von Bertalanffy (1969), for a given system the environment is the set of all objects, a change in whose attributes affects the system and also those objects whose attributes are affected by the behavior of the system. Fagen and Hall (1968), describing von Bertalanffy's concept, note that a system together with its environment makes up the universe of all things of interest in a given context. Subdivision of this universe

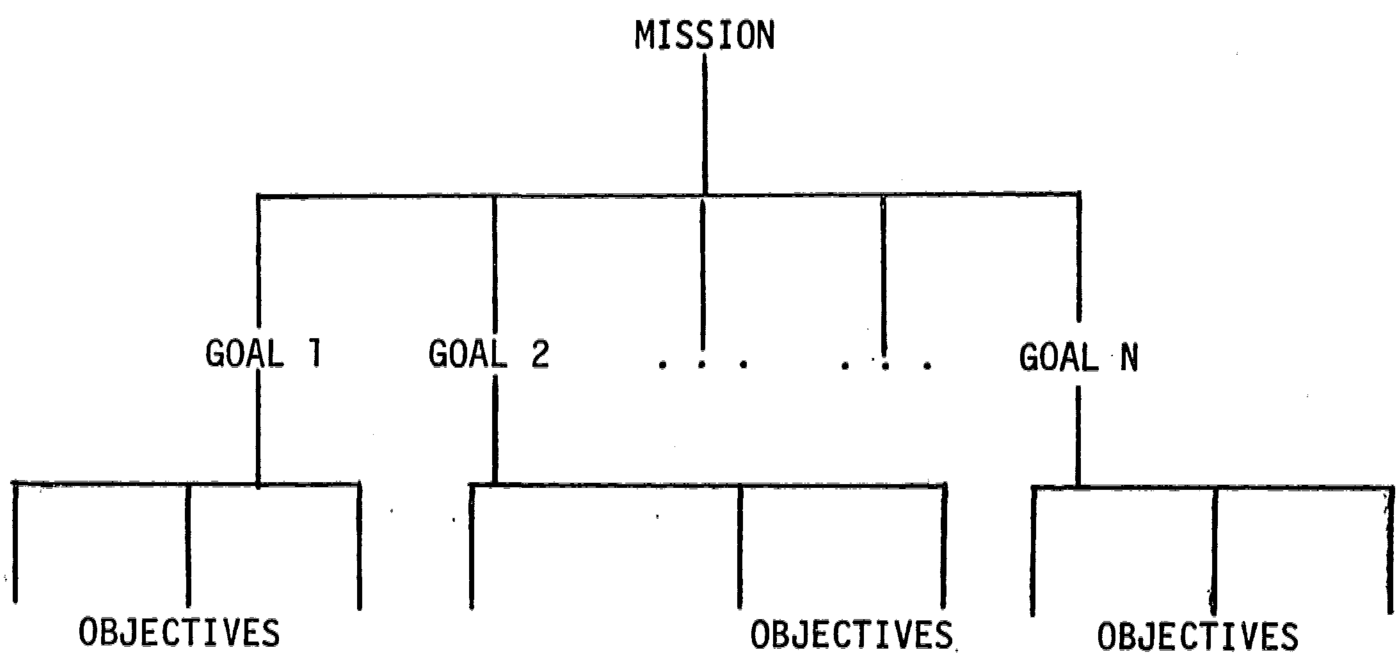


Figure 1. Interrelationships among mission, goals, and objectives

into two sets, system and environment, can be done in many ways which are in fact quite arbitrary. Ultimately, it depends on the intentions of the one who is studying the particular universe as to which of the possible configurations of objects is to be taken as the system. The concept of environment is used in classifying systems into "open" systems and "closed" systems.

Open systems are typical of those found in the natural category. An open system trades its materials or energies with the environment in a regular and understandable manner. Most business activities are conducted in an environment of an open system. Opposed to this are closed systems, which operate with relatively little interchange of either energy or materials with the environment.

It can be noted that von Bertalanffy's definition does not really contradict that of Churchman. They talk about two different types of environments. Churchman's concept of environment in terms of constraints holds true for all systems--both open systems and closed systems. However, von Bertalanffy uses the environment to indicate the attribute of the whole system with respect to its interaction with the environment; that is, von Bertalanffy's conception helps one to distinguish an open system and a closed system.

In a typical open system, the performance of the system in terms of its mission is stationary for a given time. The mission of the system--thus the goals--can be subject to change as situations warrant. The mission is amenable to change according to changes in the environment. As the open system's performance affects (alters) the attributes of the environment, the environment's control is also affected. So, it is necessary to utilize the concept of the feed-back loop when one describes an open system. The concept of feed-back loops is depicted in Figure 2.

Feed-back loops operate in situations where the outputs from the system are responsible for modification of the system's future outputs. In these situations, the mission of the system is not stationary. The mission of the system is susceptible to change. The change is due to changes in the attributes of the environment, and the environmental change occurs as a result of the system outputs.

For the purpose of this study it seems necessary to define both types of environment. The mission of the educational systems is determined by Churchman's type of environment. The outputs of the educational systems are designed to effect von Bertalanffy's type of environment. Besides, the mission of the educational system is to satisfy the needs of the society (environment), and the society determines the mission of the system. Any change in needs of the environment (society) will result in changes of the system mission. Hence, it is appropriate to understand both types of environment.

Resources. Resources are those services such as humans and materials that are necessary for system performance. Resources are synonymous with

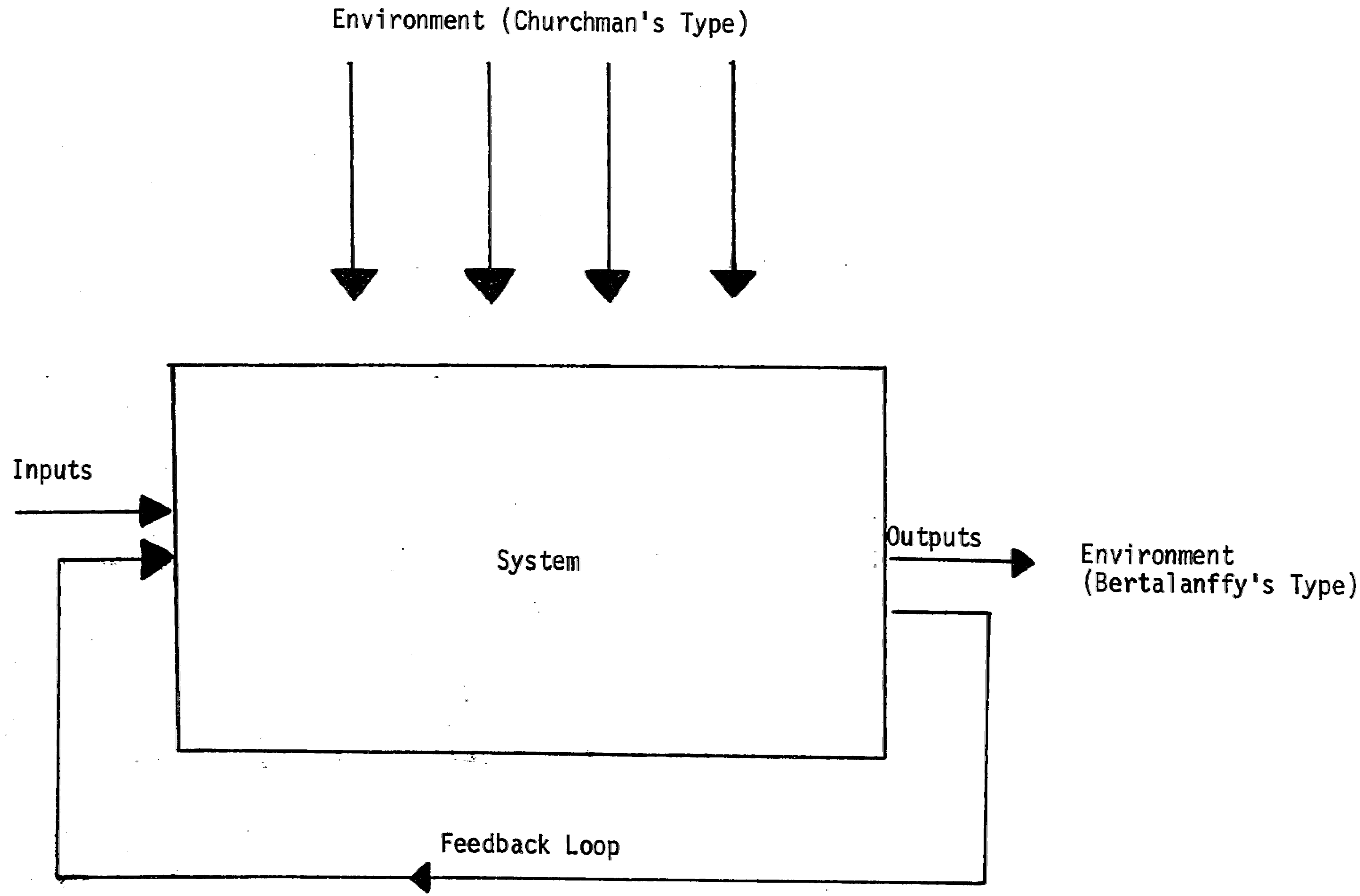


Figure 2. A feedback loop system

facilities. Resources are directly under the control of the system. The system can use the resources any way it wants to attain the overall objective. The resources are men, materials, equipment, capital, and time. Main resources are offered by the environment, and subsidiary resources are developed within the system itself (e.g., computer facility). Main resources are those without which the system cannot function, for example, capital.

All types of resources have limitations in their capacities. These capacities might be either true limitations or arbitrary limitations assigned by the environment or within the system itself. For example, human labor may be limited to eight hours a day as set by the labor department, which is arbitrary. However, the capacity of a computer may be limited to some finite memory core storage. Similarly, the wage for the human resources may be a standard determined within the system.

The system has to operate within the limitations on the main resources, imposed by the environment. Limitations on main resources are usually inflexible. Sometimes resources are differentiated from facilities. The facilities are those which are immovables such as buildings, space areas, or lighting in the buildings. The resources are movables such as typewriters, men, and machines, etc. As such, increments in capacities in facilities would require more energy expenditure and money than the resources. Again, increasing the resource capacities is easier than increasing the facilities.

The resources cannot be increased indefinitely without increasing the facilities. For example, the number of men and machines can be increased only up to what the facility (the building) can accommodate. In order to increase the number of men and machines, the capacity of the building also should be increased. Thus, some of the resources are dependent on the facilities.

For our purpose it may be worthwhile not to differentiate between the facilities and the resources, but rather to encompass both under the general concept of resources. Resources then can be divided as immovable, movable, intangible, and tangible resources. Immovable resources are those resources which cannot be easily moved and those whose capacity can be increased only with considerable investments. Movable resources can be added with less difficulty and are adequately available when necessary, such as personnel, office machines, etc. Intangible resources are those which are called main resources allotted by the environment, such as capital. Tangible resources are those which can be manipulated at discretion by the system. For example, the total money available may not be increased at the system's will, but the system can dispense the available money.

Components. The next aspect of the system is its components. System components refer to those "operations" or functions that are necessary for total system performance. Components and subsystems are synonymous.

Subsystems are divided into (a) primary and (b) secondary. Primary subsystems are those whose performance is critical to total system performance. They are central to the operations. The secondary subsystems are satellite to the central operation.

(In business and industries, some investigators have used subsystems or components synonymous to divisions or departments of an organization. For our purpose, particularly in education, the nomenclature of departments or divisions may be misleading because all the departments hold primarily the function of teaching.)

Relationships in a system are often referred to in terms of interconnection between objects or parts of the systems. Particularly, dependencies of activities of some parts on other parts, and interdependencies between parts for their activities are described often as relationships. The relationships are essential for the system activity. This is what keeps the system meaningful. Without the notion of relationships, the concept of systems is meaningless.

Refinement in the definition of relationship is necessary to suit our purpose and the way a system is viewed. For our purpose, relationships are defined as dependencies between components. As stated earlier, components refer to functions or operations in a system. Accordingly, relationships have meaning with respect to function rather than objects. Thus we are interested in functional relationships rather than relationships between materials or objects. Relationships between processes rather than products (materials) are stressed.

Management. The management as part of the system deals with maintaining the activities of the system so as to achieve the mission. It is the internal regulating agency which not only controls but also, if necessary, modifies the components. It establishes the internal constraints and standards (criteria) for the subsystem performance. It serves as information storage and communication media between subsystems. Thus it sets the component goals, allocates the resources, and controls the system performance. Its main task is to supervise and monitor the system activities.

## System Evaluation

System evaluation deals with measurement problems of the system. The evaluation study gives a measure or a set of measures on the system performance--how well the system serves its mission. It tells one what the system accomplishes and how well it fulfills its mission. As such, the system analysis is prerequisite to evaluation. One has to know the desired performance levels and actual performance levels. Measures of performance of the system and its subsystems are needed to find out how the system performs under actual operating conditions. These measures can be selected intelligently only from the information furnished in a system analysis.

The evaluation phase of the cybernetic management cycle consists of three stages: (1) establishing criteria which, as previously defined, assign levels of desirability (utility) to output and outcome states, (2) comparison of desired output states with the assessed states as determined in the analysis phase, and (3) identification of those indicator variables that fall within the desired range.

### System Development

In the engineering field, system development usually deals with the problem of designing new systems. However, for our purpose, system development means redesigning those systems that do not meet acceptable levels of performance. It represents an attempt to solve a continuing series of problems by planning, gathering information, making decisions, solving problems, communicating information, and implementing decisions. Modification or redesigning of an existing system is preceded by system evaluation which, in turn, is preceded by system analysis.

The design phase provides for the judgments regarding whether those systems that do not achieve the desired outputs and outcome states should be eliminated or modified. Planning at this phase requires specification of a set of alternatives and a procedure for selection of an alternative system arrangement that appears to complement system goals.

After the system is properly defined and the type of system study is chosen, what an investigator needs is a tool to carry out the study. The tool that is available for system studies is models. As Chapanis (1961) defines it, a model presents only an "as if" situation of a system. A model is an aid to representing a system. Models are symbolic tools, the tools that one uses in attempting to determine if the combination of the data and the condition is sufficient to explain the observed phenomenon.

## Models

### Needs for Models

In assessing and evaluating the activities of the USOE-funded research and development centers, Brownell (1968) declares that many small projects are undertaken and treated as completed once the final reports are prepared, without solving the problem. He notes that a large number of the projects did not make clear how their objectives were related to the missions of the organizations. Brownell suggests establishing quality control procedures as in consumer product industries. Before the products are available for implementing in school systems, the center should be responsible for checking and double-checking the base data, procedures, interpretation of data, and the conclusions of the projects as to accuracy, reliability, and validity. The work being carried out at the centers should concentrate on the problem existing in the school systems. Brownell questions the adequacy of knowledge that the researchers possess in regard to the school system. He feels that researchers are assuming that they know more about school practice than they really do. He advises that researchers should be aware of (1) the range in practices which exists between school systems and within a school system, and (2) the interrelatedness of variables with which a school system and an individual deal which may influence pupil behavior, staff performance, community attitude, costs, preparation, and record-keeping time for a teacher.

Taking a similar view, Bloom (1968) suggests that the reason the performance of the centers is not at par can be attributed to their failure to build dynamic models. Models are the symbolic tools of the system under study, the tools that one uses in attempting to determine if the combination of the data and the condition is sufficient to explain the observed phenomenon. The goal in model-building is to construct a reliable representation of the system. Models not only help one to visualize the systems; appropriately constructed models also indicate the outputs as a result of changes in variables.

## Descriptive Models

There are basically two types of models: descriptive and analytic. The descriptive model is a pictorial or conceptual representation of the components, indicating the relationships between them without specifying the nature and extent of relationships; no overall system performance is mentioned. A descriptive model will facilitate knowing the starting point in the system analysis. It also helps to put the information together.

Descriptive models help to determine the success or failure of the system analysis. The success or failure rests only with the investigator in dealing with the total problem. The success of system analysis and the validity of its solutions are influenced by the ability of the investigator to represent the real world of the problem in symbolic form. The systems analyst moves from the real world to various symbolic tools (models) to analyze what is observed. The product from a system analytic study is the construction of a reliable representation of the system. This brings up the second type of model--analytic models.

## Analytic Models

An analytic model or a dynamic model realistically imitates the system being studied. The five aspects of the system--performance, environment, resources, components, and management--(Churchman, 1968) are expressed such that an analytic model can be constructed. When this is done, components are expressed in terms of their significant attributes. Environmental constraints are then defined, and the resources are described in terms of feasibility and accessibility. Finally, management controls are developed and described.

## Problems in Systems Redesign

It is expensive and risky to experiment with the real system for the purpose of redesigning it. The clients do have the right to know the validity of the solutions. They would also like to know the alternatives. However, it is almost impossible to experiment with the real systems on site without the risk of breakdown of the system and high cost. So what is needed is a procedure which will circumvent direct interference in the real system.

The simulation process can help to avoid the direct confrontation with the real situation. The key element in the simulation process is a model which can be one of three approaches: constructing a physical representation, applying mathematical expressions, or using a dynamic model.

## Types of Simulation Approaches

The traditional and perhaps most familiar approach is using a physical representation that can be readily manipulated. The wind-tunnel, long used in aeronautical engineering to study the behavior of aircraft under varying flight conditions, is an example of a physical model. Physical models, despite some obvious advantages, are not usually economical and are time-consuming to construct and experiment with. A mathematical model is usually given in the form of sets of equations, expressing a system's characteristics. It contains a very high level of abstraction. The problem in the "behavioral" systems where humans are part of the components may involve many variables, many parameters, and functions which are not well-behaved mathematically. Hence, these problems make it extremely difficult to find solutions for the exact mathematical models. For the "behavioral" systems, simulation using dynamic models seems to be promising.

The dynamic model indicates not only what changes occur in parts of the model as a result of a change in one part, but also how changes take place. Similarly it will help to show what changes have to take place in order to get certain outputs. In other words the dynamic models are simulatable. The description covers the interactions between the variables, the attributes of the variables, and the constraints which limit the system performance.

## Need for a Meta Model

From the statements made by Brownell and by Bloom, it is clear that the USOE-funded R & D centers should concentrate on developing dynamic models. However, as Bloom (1968) states:

> It is not entirely clear whether the difficulties in developing such theories or models is attributable to the present stage of thinking in the field of education or whether it is attributable to the inability of particular teams of workers to think through a dynamic model or theory which they can use as a first approximation of the phenomenon they are studying.

Whatever the difficulty is attributable to, it is imperative that something should be done to tackle the problem. One way to alleviate the present situation is to provide a plan which could assist investigators in building models. The investigators can follow through the steps in building models. At each step the investigators can think through the problems and the information required in building models. This will enhance their thinking process in the field of education in terms of model construction. This plan will systematically suggest activities that are *sine qua non* for model building. These prerequisites serve to generate projects. The development of such a system--a "meta model" is proposed in this study.

## Meta Model

It is clear from Brownell's and Bloom's statements that the educational R & D organizations should concentrate on building models. A scrutiny of their statements reveals that the models which the educational R & D organizations should concentrate on are dynamic models. As stated earlier, the present lack of training on the part of educational investigators in building models requires a ready-made procedure to build models, particularly models that are amenable to computer simulation.

One way to tackle the problem of building simulatable models is to determine what is needed for communicating with the computers. Once the means of communication process is established, *i.e.*, the appropriate language is chosen, then corresponding requirements (input) to the language will pave the way for the model-building. That is, it is reasonable to suppose that there is a one-to-one correspondence between loading the language and model-building. Thus, the computer simulation language and model-building are isomorphic to each other.

### Computer and Simulations

The problem is to find a way to activate the analytic models in the simulation process. Ways and means of conducting the simulation process are becoming relatively simple. Using computers, models of existing and proposed complex systems can be experimented upon without the high cost, risk, and expenditure of time involved in experimenting with the real processes. Hypotheses can be formulated and tested using simulation processes on computers, and decisions, rules and alternatives can be obtained, evaluated, and compared. More ready and timely forecasting and projecting into the future may be accomplished.

In order to use a computer, the investigator must be able to communicate with the computers through computer languages. Very often the computer languages that are used for simulation purposes are classified into two major types: continuous-change models and discrete change models.

Teichrew and Lubin (1966) describe each type as follows: Continuous-change models are used when the system under study shows a continuous flow of information or materials counted in the aggregate rather than as individual items. The systems are usually represented in mathematical equations that describe rates of change of the variables over time. Such models are generally used to describe electronic or mechanical systems. The simulation process requires special type computers such as analog or ambilog computers. On the other hand, the discrete-change models do not require any special devices other than general purpose digital computers.

In discrete-change models, the change in the state of the system is conceptualized as discrete. The components of the system perform definite and prescribed functions; inputs flow through from one component to another, requiring that some activity take place at each component; and the components have limited facility (resources) for their activities.

It is assumed that behavioral systems can adequately be explained by discrete-change models. The behavior can be treated as discrete over time without losing much information about the performance. It can reasonably be assumed that the behavior is not continuously changing but rather changing over discrete time units. Another advantage of treating behavioral systems as discrete-change systems is that the simulation processes can be carried out without much ado because the general purpose computers are more conveniently accessible. Simulation languages which are well authenticated for the discrete-change models are available at various levels of sophistication.

## Simulation Languages

There are a substantial number of simulation languages for discrete models. Each of the languages offers some features suitable for the particular problem or class of problems at hand. Six major languages are GPSS, CORC, CLP, GASP, SIMSCRIPT and CSL. The investigator has to be selective in choosing a language according to the nature of his problem. For our purpose, the GPSS seems to be quite appropriate, since it is probably the most versatile and widely used. It is provided and maintained by the largest manufacturer of electronic computers, IBM, and it is currently used by many computing centers, particularly in university situations.

The GPSS, or General Purpose Simulation System, consists of a package of subroutines which are called blocks. Each block stands for a specific operation. The blocks are arranged in a particular order specifying the relationships between blocks, and the arrangement of blocks form the system.

The user, i.e., the model builder, need not have prior programming experience or knowledge of the computer used. What he has to do is arrange the blocks in such a way that the arrangement imitates the system under study. Thus model building is basically the arrangement of the GPSS blocks.

The GPSS is most suitable for modeling input-output systems. In a typical input-output system, a "throughput" is created and flows through the system. The characteristics of the throughput are modified in the processes. The throughput then is outputted from the system into the environment.

The blocks in GPSS operate on the throughput. The basic process on the throughput takes place when it moves from one block to another, each block performing some specific action. The sequence of blocks arranged according to the temporal flow of system activity is called a "flow-chart." The flow-chart describes the system configuration, decision rules, and all logic associated with the flow of the throughput in the system, and is, in effect, a "picture of the simulation model."

A school system can serve as an example to illustrate an input-output system. A student as throughput enters a school system. When he enters, he carries certain attributes with him, such as attitude, personality, intelligence level, knowledge in different areas of subjects. As he passes through from one grade to another, changes take place in his attributes; that is, he gains more knowledge, his personality changes, his attitude changes, and his intelligence level changes. Thus each grade level performs some action which changes his attributes. The grade level can be considered as one example of a block in the GPSS.

Events take place when the student moves through the system. Such events may be curriculum change or change of field of study. The event modifies the student's attributes, which may in turn decide the student's behavior, such as which courses he will take next, what grade he will be promoted to. At given decision points, decisions are made by or for him, such as promotion to the next grade, the selection of curriculum, or preparation for employment. There is a logic associated with the decision process.

The student's flow through the system is determined by the rule structure of the system. The throughput (student) leaves the system after some period of time either because adequate changes have taken place in his attributes (graduation), required changes did not take place in his attributes (failure), or because of an arbitrary decision by the student (dropout). Thus in a school system, a student enters the system carrying attributes, passes through stages (operations) of changes in his attributes, and leaves the system.

Schematically, a school can be represented as follows:

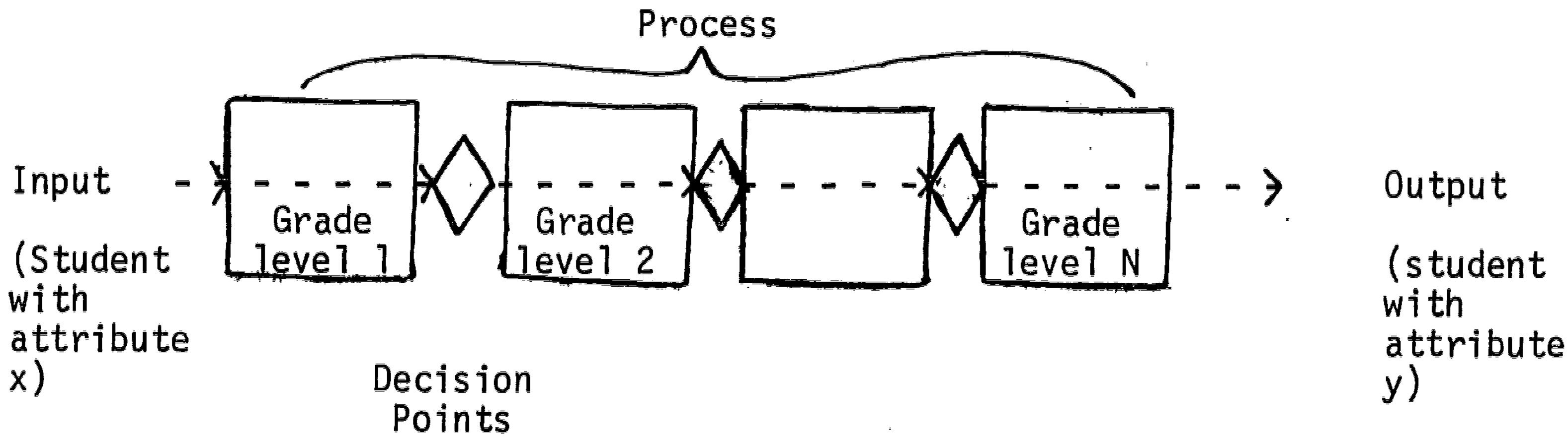


Figure 3. Schematic representation of school

## GPSS and Systems Terminology

The systems concept and its terminology have been discussed earlier. A model is the representative of the real system. Models are symbolic tools to explain the observed phenomena in the system, and the GPSS can serve as a basis to build models. As such, it is deemed necessary to relate the GPSS to the systems terminology. An attempt is made in this section to relate the semantics used in GPSS with the systems terminology.

The GPSS is built around a set of blocks (system activities). These blocks are essentially equivalent to the components of a system. The principal entities in GPPS are described as Transactions, Facilities, Storages, and Logic. The transactions are dynamic in nature in that they are the particles that flow through the system according to the sequential arrangement of blocks. They are created and destroyed as required during the simulation. The principal attributes of the transactions are referred to as parameters which are used to define the properties of the transactions. The parametric values are assigned by the functions specified by the model builder. These value functions can be considered as the constraints imposed by the environment of the system. The model builder obtains the functions from the systems analysis, *i.e.*, through research.

The facilities and storages can be considered the resources of the system. These entities are representative of the equipment in the system used in the processing of transactions. Facilities are time-shared, and each facility can be considered as a service unit. A facility provides service to one transaction at a time. To obtain service from a facility, transactions have to wait in line, if the facility is in use. On the other hand storages are space-shared. For example, a storage can be a classroom. Since more than one transaction can occupy a storage, many transactions can obtain the service of a storage simultaneously. Counseling serves as an example of the logic entities. Though they also perform managerial functions they can be considered resources available in the school system. The counselor helps to decide what course of action a student should take, such as the field of study. Counseling helps to make decisions based on the student's attributes, i.e., his interests, his achievements, and other parametric constraints.

The indicators of the system's performance are probided by the statistical entities. The statistical entities store the required information and help to retrieve the stored information. The information that can be stored includes the status of a storage at a given time, the rate of service by a facility, total waiting time for a transaction to obtain services, average waiting time to obtain services, present state of the system, etc.

The operational entities are the processing blocks. They perform operations on the parametric values of the transaction. They change the values, assign new values, and also route the transactions. They provide the logic of the system in that they instruct the transactions where to go and what to do next. This type of handling the transactions performs operations similar to system management functions.

A classification of the GPSS blocks is helpful in viewing the blocks in their respective operations. The blocks can be classified under six categories: input operators, handling operators, modifiers, information storage, information retrieval, and output.

The blocks under the input operators are responsible for the generation of transactions. The generation of transactions is considered as the system activity and probably the initial phase of simulation. Without the inputs in an input-output system the system is idle, since there is nothing the system can operate on. The handling category contains those blocks which route the transaction from one block to another. Their activity is essentially determining the flow of the transactions. The parametric values of the transactions are used in determining the flow of the transactions, and the blocks under the modifier category assign and change the parametric values of the transactions. The parametric values are the attributes of the transactions. Information storage blocks can be used to store necessary information about the system status. Whatever information is stored can be obtained by the information retrieval blocks. Both the information stored and retrieved and the attributes (parametric values) are numerical.

The output category contains those blocks which terminate a transaction. They remove the transactions from the system. The six categories and blocks under the categories are given in Table 1. Using the blocks and arranging them in a sequential pattern yields a model of a system. Thus, GPSS can be useful in providing a language for modeling.

A flow-chart, which is a picture indicating the flow of a transaction through a system, could be a starting point to build a model. To flow-chart a system, information on the processing operators, handling operators, decision rules, decision points, resources, characteristics of the transactions, performance indicators and such other system activites is required. The procedure for obtaining such information necessary to construct models is called "meta modeling."

The meta model serves to channel model-building activities to a desired course of action by providing a general framework for gathering specific information necessary to build models. Information so attained can be used to flow-chart the system and also to provide information regarding specific parametric values associated with each block of the flow-chart. Thus, the meta model provides an underlying structure for the generation of models which serve as the basis for description and explanation of various fields of inquiry.

A logical starting place for the system's inquiry is the system's performance. Information on the system's performance helps one to understand the general purpose of the system. The system's mission, goals, and objectives give broad general information about the activities of the system.

Table 1. Classifications of GPSS blocks[a] under six categories

| Input | Handling | Modifier | Infor. Stor. | Infor. Ret. | Output |
|---|---|---|---|---|---|
| Generate | Split | Assign | Save Value | Tabulate | Terminate |
| | Assemble | Index | | | |
| | Match | Mark | | | |
| | Queue | Priority | | | |
| | Advance | Alter | | | |
| | Gather | | | | |
| | Gate | | | | |
| | Transfer | | | | |
| | Test | | | | |
| | Select | | | | |
| | Loop | | | | |

[a]Only the most generally used blocks are included.

Once information concerning the system's performance is obtained, the description of the GPSS blocks and the information required to load the blocks would facilitate flow-charting the system using the GPSS blocks.

Determining the System's Performance

The system's performance has meaning in three mutually interdependent terms: mission, goals, and objectives. The mission is the ultimate purpose of the system and is usually implicitly stated in the mandate for the system design. However, a problem arises in formalizing in explicit terms the intent underlying the system mandate. Whatever one comes up with may be disputable and controversial, but no matter how difficult the task, it is absolutely necessary to have a mission statement.

In this section, a procedure is outlined for arriving at a mission statement. It should be emphasized at this point that the assumption is that certain information facilitates the formulation of a mission statement.

The procedure is based on data-gathering and decision-making techniques. Depending upon the nature of the information the procedure contains questions, multiple-choice items, and open-ended items. In the multiple-choice items it should be emphasized that multiple categories may be relevant to determine the mission statement. Open-ended questions may require decision-making based on the previously obtained information. Answers to the following questions may provide a base for determination of the system's mission statement.

1. Is the mandate for the system established:

(a) by government agency?
(b) by legislation in the Congress at the federal level?
(c) at the state level?
(d) locally at the institution?
(e) by society?

2. According to the intent of the mandate, is accomplishment of the mission useful to:

(a) the general public?
(b) private institutions?
(c) public institutions?
(d) government agencies?

3. Is the method of communication of mission awareness:

(a) public communication media (newspapers, TV, radio)?
(b) government publications?
(c) Senate or Congress minutes (acts or laws)?
(d) private communications (letters, oral)?

4. Is the intended purpose of system stated:

   (a) implicitly (leads to different interpretations)?
   (b) explicitly, in easily identifiable form which does not lead to controversy?

5. If system intent is not explicitly stated, is clarification done by:

   (a) personel interpretation sufficient?
   (b) through government agencies?
   (c) through seminars and conferences?

6. Is the nature of the mission for:

   (a) academic or scientific interest?
   (b) social change?
   (c) human basic need satisfaction?
   (d) education change?

7. What is the estimated time required to complete the mission?

   (a) more than two decades
   (b) one-two decades
   (c) less than ten years, but more than five years
   (d) less than five years

8. Is the mission:

   (a) ever-present or continuously operating (no end point)?
   (b) fixed to a terminal point?

Using the answers to the previous questions as a guide:

9. State the mission of the system in terms of general performance.

10. Are system personnel (persons working within the system) aware of the mission?

11. If they are not aware of the mission or if they hold misconception about the mission, communicate to them either face-to-face, through writing letters or memos, or through seminars and conferences.

After the mission is clearly stated, the goals can be derived from the mission. One way to understand the goals of the system is by segmenting the mission by time periods, phases, or functions. Mission segments are classifications of activities which are arbitrarily selected on the basis of homogeneity of operations or coherence within the segments and easily identifiable start and stop points. Each segment state has a desired outcome state. This desired outcome state is called the goal. Once the mission is made clear, the feasibility of segmenting the mission can be explored. A procedure is given below which can be used to derive goals from the stated mission.

1. State the system's mission.

2. Segment the mission functionally, by phases, or by time periods.

3. List segments or major activities required to perform the mission.

4. For each segment identify the starting point and end point.

5. Indicate the relationships between segments.

6. Identify the sequential segments. The sequential segments' starting points depend on the end points of other segments. Thus, two segments are sequential if one segment cannot start before the completion of another.

(a) Indicate by graph or picture the major sequential activities required to accomplish mission.

7. Identify parallel segments. (Parallel segments can function simultaneously without depending on any other segments.)

8. Identify the primary segments. (Primary segments are the essential activities for accomplishing the mission.)

9. Identify the secondary segments. (Secondary segments are the supporting activities for maintenance of the system.)

10. Rank the primary segments in order of their importance in accomplishing mission.

11. Similarly rank the secondary segments according to their supportive roles.

12. Identify the purpose of each segment. What is a segment to accomplish? List the desired outcome for each segment.

13. Give a name or code for the purpose (desired outcome) of a segment. These form the goals of the

14. Indicate the priorities of the goals.

After the goals are formulated, the system personnel should be notified about the goals. Formulation of the goals from the mission require expert decision-making skill. Thus, the success of formulating appropriate goals depends on the skill and ingenuity of the decision-makers.

The mission is segmented to formulate goals. As noted earlier, each segment has a desired outcome state. A segment contains measurable units which can be used to form critical levels to signify the desired state. These desired outcome states form goals.

In order to achieve a desired outcome state, certain critical levels of system output should be accomplished. Achievement of the desired output states are the objectives. Variables defining the outputs should reach critical levels in order for the outputs to achieve the desired levels. These critical levels are the necessary conditions to establish the desired states of the outputs.

Once the goals are formulated, the necessary objectives for each goal area can be established. In order to establish objectives, it is desirable to select one goal at a time. The selection process can be based on the rank levels of the goals. For example, the goal which received the highest rank could serve as the first goal for which the objectives are decided on.

A procedure is given here which can be used to determine the objectives for a given goal.

1. Select a goal.

2. Determine the measurable units of the goal.

3. Determine the crucial dimensions of the variables of the goal. These dimensions are used in forming the objectives of the goal. In other words, determine the dimensions of the outputs that are necessary to accomplish the goal.

4. For each output, determine whether the variable is continuous or discrete.

5. Determine the critical value that each variable is to achieve.

6. What are the sequential outputs?

7. What are the parallel outputs?

8. Indicate the interdependencies between the outputs.

9. Set the critical range for each output variable.

10. Establish the critical boundaries for the variables.

11. What are the variables that should reach their maximum levels? What are their maximum levels?

12. What are the variables that should reach minimum levels? What are the minimum levels?

13. Indicate those variables whose presence may offset the desired output. These variables are called control variables.

14. Establish the measurement procedure for the variables, _i.e._, establish output measures.

15. List the objectives.

After establishing objectives corresponding to a specific goal, determination of objectives for the next goal is carried out.

Determination of the system mission, goals, and objectives helps to understand the general characteristics of the system. Statements about the mission, goals, and objectives give a general notion of the system. Once the general characteristics of the system are understood, flow-charting processes involved in the system could be attempted. Since flow-charting a system involves temporal or sequential arrangements of system activities, the first step in flow-charting the system requires identification and categorization of system activities. The GPSS blocks can form a viable tool for grouping the system activities. Hence, it is necessary to describe the GPSS blocks and information that is required in order to use the block in the block diagram (flow-chart). The GPSS blocks are described briefly in Appendix A. Parametric requirements for each block and questions that can be asked about the parameters are given.

Bloom (1968) points out that persons engaged in educational research do not generally think in terms of model construction. Specifically he states, "Perhaps an R & D center needs to be reminded repeatedly that impractical theory or model building may be its most practical work." It is quite clear from Bloom's statement that the educational R & D organizations should be building models of the systems under study. Building models serves as a radix for formulating research and development projects. It aids particularly in the generation of projects at the systems analysis stage and systems redesign stage.

Systems analysis provides the information necessary to build models. Here, a category of required information forms a research area and the information necessary to build models demands research activities. Areas such as the mission, goals, and objectives of the system, the environmental constraints, the effects of systems outputs onto the environment, resources availability, major and minor functions in the system, and the management of the systems form the basis for gathering the information necessary to build the models.

The evaluation phase helps to identify the problem areas for further research. This phase includes establishing appropriate criterion measures for the system outputs and outcomes, methods of measuring, data collection, analyses, and interpretations for further research areas.

In the redesigning phase, the problems that were recognized in the evaluation phase form research questions to be answered. In solving the problems, one must recognize the constraints that are beyond the experimenter's control, the modifiable variables, the locus of the problem, and possible alternatives. Determining possible alternative solutions to the problems demands research activities.

Once possible solutions are obtained, methods of implementing the solutions warrant the developing of new systems. All these questions are generated by the appropriate models. However, "It is the lack of a powerful theory or dynamic model which represents the most serious lack in most of the R & D centers " (Bloom, 1968).

The meta model forms a radix for model building activity. As such, the meta model provides an underlying grammatical structure for the generation of models which serve as the basis for description and explanation of various fields of inquiry.

More specifically, the meta model helps to flow-chart the system under study. The flow-chart so produced is the fundamental framework of a model of the system. The meta model guides the flow-charting by providing specific questions in constructing models. Plugging answers to the questions (loading the meta model) the meta model yields a specific model. Hence, the answers provide both a structural and a parameter basis for a specific model. That is, those answers that pertain to selection and sequence of block activities structure a particular model, while the answers to specific block questions provide the parameter information necessary to actuate the block.

The meta model also provides continuity in model building and is useful in monitoring the progress made toward building a model. It helps to upgrade the model with added information. For each stage in model construction the meta model supplies questions to be asked in model building. By so doing, it specifies the ingredients that are necessary to build models. These ingredients can be compiled from the way the system under study is defined.

A system can conceivably be broken down into subsystems; that is, the sub-organizations of the total system that are functionally similar. Each subsystem forms a system by itself. The ingredients and characteristics that determine a system also govern a subsystem. As the meta model dictates questions in modeling a system, so the meta model also helps in constructing models of subsystems. The same procedure that governs modeling a system also determines modeling a subsystem. In fact, the model of the entire system may be constructed by first modeling the individual subsystems and then linking the individual models into a comprehensive model of the entire system.

Since the meta model requires answering questions in constructing models, the activities of collecting parametric information so as to provide answers to questions help to formulate projects. When activities are grouped under some meaningful categories, a category (bundle of internally related informational requirements) may then be defined as a project. Thus a set of information-gathering activities in model building forms a project. For example, activities concerning input (transaction) information such as the nature of inputs, their arrival rate, characteristics, and population attributes can form a project. A set of projects which can be categorized together because of their similarity and inter-dependencies can form a program of research. For example, projects concerning modeling a subsystem of a school system can form a program.

Depending upon the complexity of the system and the specificity of the model, project quantities vary. A highly complex system and very detailed modeling of the system would require a greater number of projects to furnish answers to load the meta model than a not-so-complex system.

## Project Specification

After projects are generated, specifications are laid out concerning the content and methodology of the projects. The content specification of a project refers to the information required to be supplied at the completion of the project. The information content helps to assign utility values to the project based on the importance of priority level of the information content. The projects which contain high priority information would be assigned high utility values, and the projects which yield less important information at their completion would have lower utility values. The specifications indicate what each project would accomplish in terms of power, precision, and reliability of the information to be supplied. Further, the type of information-gathering mechanism is also specified and depends upon the quality of information desired.

The quality level of information ranges from soft information to hard information. Soft information is very broad, general, and occasional, while hard information is very precise, narrow, and reliable. The method of collecting information dictates the level of information obtained. Information-gathering techniques can be conveniently categorized under five categories.

The first category deals with casual or anecdotal observation of the phenomena under study. This method does not require any sophisticated tool to collect data and can result in a general picture of the system under study. One drawback in this procedure is that important variables may be overlooked, and relatively unimportant variables may draw greater attention. This method is better suited to observing problems than obtaining solutions to the problems.

Analysis of relevant existing records and documents forms the second type of information-gathering mechanism. This method would result in describing existing states of the system. It can furnish more detailed information than the first method; however, analysis of existing records can furnish only a historical account of system activity, nothing more. Thus this method would help to describe an existing system according to a prescribed set of dimensions.

The survey research technique can be used to collect new information. Information which could not be obtained by the second method can be obtained by this third method. Using this method, information can be gathered from the situations to which results are intended to apply. This method gives more detailed information about the nature of the phenomena under study and allows the gathering of information pertinent to the problem solutions.

The fourth method, namely computer simulation techniques, requires skill in model construction and computer programming experience. This technique can be applied to obtain solutions to problems. The simulation helps to control the variables, to increase the power of variables, and to obtain alternative solutions to problems. The information obtained from this method is reliable and precise.

The last method of gathering information deals with laboratory experimentation. The laboratory experiment can be carried out to check the validity of the solutions obtained from other methods. Information obtained through experimentation is precise and valid, but restrictive in generality.

The project specifications deal with detailing information content and method to obtain the information needed to produce dynamic models. Not only what a project should produce, but also the procedure to obtain the information is specified. Specification of projects generates a set of projects and, as a consequence, the need for selection.

## PROJECT SELECTION MODEL

Since a greater number of projects may be generated than the financial resources can accommodate, the decision on which projects should be selected is important for project management. An R & D center's accomplishments over a period of time is dependent upon the effective utilization of human and financial resources. Effectiveness will depend on careful planning that starts with project selection. Project selection determines the course of research.

In this regard, project selection models are important, and, consequently, such models as have appeared in the literature are reviewed in the following section.

### Literature Survey

Most of the research work in program planning and project selection has been done for the industries where the development of new products or reducing the manufacturing cost of established products is the main concern. The work has been done by the operations researchers who have formulated the problems and the models in sophisticated mathematical terms. The variables usually considered are cost, forecasted market gain, price of the products, life span of the products, and competition from other producers.

Baker and Pound (1964) surveyed just over eighty references dealing directly with part or all of the R & D project selection problem. Though many models have been proposed by the operation researchers and management scientists, Baker and Pound found only a few references indicating the test and utilization of formal R & D project selection methods. Baker and Pound reasoned that this might be due to either a hesitancy to publish such confidential material, a real lack of testing and use, or some combination of both possibilities. From all the models referred to in the literature, they singled out ten because only these contained relatively complete proposals for the solution of the general R & D project selection problem. Only one of them was widely known among the users and had seen limited use.

In 1967, Cetron *et al.* (1967) did an extensive survey of the models currently available. They evaluated thirty models which included ten reviewed previously by Baker and Pound. They have described each model briefly. According to them, thirteen models used an operations research approach; eight models followed a decision theory approach; one model used an economic analysis technique; three were given mathematical treatment; and five used combined approaches from operations research, economic analysis, and decision theory.

The analysis of the thirty models led Cetron *et al.* (1967) to evolve the following features descriptive of R & D selection models: (1) utility measure, (2) probability of success, (3) originality of criterion, (4) sensitivity, (5) rejected alternatives retention, (6) classification structure, (7) time, (8) strategies, (9) system cross support, (10) technology cross support, (11) graphical display, (12) flagging, (13) optimization criteria, (14) constraints, and (15) computerization.

The thirty models were compared for features, ease of use, criteria and area of applicability. It was found that no single model possessed all the features. All of them possess utility measures, and with one exception, all include the feature of probability of success. Only six are useful for selecting research projects. The remaining models are used for selecting product development projects.

Some of the models seem to be modifiable to suit our purpose. These models and their shortcomings are discussed below.

A model developed by Mottley and Newton (1959) reduces the factors involved in the selection of industrial research to five basic criteria: (1) promise of success, (2) time to completion, (3) cost of the project, (4) the strategic need, and (5) market gain. These five factors reflect the technical, administrative, strategic and marketing areas. The proposals were to be rated by expert opinion in each field, in order to provide quantitative judgments on each of the factors. The numbers obtained were multiplied together to provide a composite score for each project which was then used to rank the alternatives. Using the project scores the research manager could make selections in relation to budgetary limitations.

The Mottley and Newton model could serve as an aid in the selection process as it gives a score to each project. However, it does not give a decision rule. Another drawback in the model is that the objectives or goals of the company are ignored in the model. The five factors which are used in computing the project score are weighted equally, with the weights indicating the degree of importance of the factors. The procedure of assigning equal weights to the factors may be disputed on the grounds that some factors should weigh more than the others. A model proposed by Pound (1964) rectifies some of the weaknesses in the model.

The "expected value" model developed by Pound considered the following four factors: (1) the environment of the problem, (2) the decision-maker, (3) his objectives, and (4) his alternatives. The model is supposed to indicate the alternative which offers the greatest expectations of realizing the objectives. Following the model, the research manager lists the objectives, then assigns weights to the objectives according to the importance. For each project, the research manager assigns values on an arbitrary scale from 0 to 10, which he feels are representative of the degree to which each objective will be attained upon completion of the project. Finally, the expected value of a project is determined by multiplying the expected degree of attainment of a particular objective by the weight of that objective, and summing these products for each objective being considered. The decision rule is to choose that project which has the highest expected value.

However, the decision rule is solely based on the expected value of attaining the objectives. It does not include such factors as technical feasibility, time period required for completion and the abilities and qualifications of the investigator.

The "scoring model" developed by Dean and Nishry (1965) seems to contain the advantages and avoid the major failings of the above mentioned models. A project overall score, W, is computed for each project. Specifically, the model is as follows:

$$W_i = W_i' + W_i'' = a\Sigma\, w_j' y_{ij}' + b\Sigma\, w_k'' \; y_{ik}' \quad \ldots\ldots\ldots\ldots (1)$$

where

$W_i$ is the total score of the ith project,

$W_i'$ is the technical score for the ith project,

$W_i''$ is the market score for the ith project,

$w_j'$ is the weight for the jth technical factor,

$w_k''$ is the weight for the kth market factor,

$y_{ij}'$ is the value for technical factor j in the ith project,

$y_{ik}'$ is the value for market factor k in the ith project, and

a, b are decision variables, a, b > 0, a + b = 1.

The problem of project selection is given by

$$\max_{x_i} \left( \sum_{i=1}^{i=n} x_i W_i \right) \quad \ldots\ldots\ldots\ldots (2)$$

such that $x_i = 0$ or 1,

and

$$\sum_{i=1}^{i=n} x_i\, m_i \leq M \quad \ldots\ldots\ldots\ldots (3)$$

The value of $x_i = 0$ or 1 depends on whether the ith project is not selected, or is selected, respectively; $M_1$ is the manpower required to carry out the project i; and M is the total manpower available in research activities. This model may be solved by the use of dynamic programming applied to a single-state variable given by the manpower resource availability (Dean and Nishry, 1965, p. 552). The solution gives the decision rule for project selection.

The three models presented so far have a common inherent weakness in that they do not contain payoff variables for individual projects. Consequently, it is difficult to include the relationship between quantity of resources expended and the likelihood of project success. A model developed by Charnes and Stedry (1964) contains the desirable feature of relating the return from a project to the effort expended on that project and is described in detail in the following section.

## A Project Selection Model

The base line to develop the Charnes and Stedry (1964) project selection model contained the following: (1) utility measure, (2) optimization, (3) constraints, (4) uncertainty, and (5) criteria for decision-making. The model which was developed has incorporated the above mentioned five features.

Utility measure refers to a project's contribution to the overall research activities. Optimization refers to the process that selects those projects whose combined efforts yield optimal expected return. In the selection process of the projects, the model considers the limitations such that the cumulative total of the resources required of the selected projects is within the total budget allotted for research activities. A first step in developing improved approaches to project selection is to reflect more adequately in models the kinds of uncertainties encountered in evaluating individual projects (Brandenburg, 1966). The uncertainty refers to the probability of successful completion of the project. The actual decision-making process is done by a method that takes into account the aforementioned features.

From the various models surveyed in the literature, the model developed by Charnes and Stedry (1964) contains the five specified features deemed most ideally suited. Therefore, it is this model which will be refined for our current use. The rationale for the refined model is described below.

A project is carried out because it would yield a certain "return" at its completion for the money expended. The return is ideally equal to the estimated utility value. However, utility from a project cannot be realized unless the project is successfully completed. Attainment of utility then depends on successful project completion. However, due to the uncertainty associated with successful project completion, it is necessary to estimate the "expected reward" from a project in order to make selection decisions. It is reasonable to assume that the expected reward E (R) from a project is expected return E (r) less the expected loss E (L). Thus,

$$E\ (R) = E\ (r) - E\ (L) \quad \ldots\ldots\ldots\ldots\ldots \quad 1$$

In educational research, it can be assumed that the project incurs loss if it is not successfully completed. Thus, if a project is successfully completed it yields full return and the loss is zero. If the project is not successfully completed, the loss is equal to return. We have to estimate the expected return, E (r), and the expected loss E (L), in order to calculate the expected reward, E (R).

From probability theory, E (r) is a function of the probability of successful completion and the return, and is defined as

$$E\ (r) = r\ .\ P\ (s),\ \ldots\ldots\ldots\ldots\ldots\ldots\ 2$$

where r is return from a project, and P (s) is the probability of successful project completion. If P (s) is the probability of successful completion, the probability of not completing the project is equal to (1 - P (s)). Thus,

$$E\ (L) + L\ .\ (1 - P\ (s))\ \ldots\ldots\ldots\ldots\ 3$$

By substituting the expressions 2 and 3 in expression 1, we get

$$E\ (R) = r\ .\ P\ (s) - L\ .\ (1 - P\ (s))\ \ldots\ldots\ 4$$

Simplifying the above equation, we get

$$E\ (R) = (r + L)\ P\ (s) - L\ \ldots\ldots\ldots\ldots\ 5$$

Equation 5 indicates that the expected reward is based on the variable P (s).

The probability of successful completion of a project is assumed to depend only on the money expended on the project. However, it is also true that each project has some probability ceiling which cannot be exceeded by expending additional resources. This is called the limiting probability, or asymptotic probability. Limiting probability refers to the condition where the probability of successful project completion cannot be increased even with an infinite amount of money, indicating that the probability of successful completion can never be greater than the limiting probability. The relationship between the amount of dollars expended and the probability of successful completion is assumed to be a monotonically increasing function. As the dollars invested increase it appears reasonable to assume that the probability increases exponentially. Initially as the dollar amount increases, the slope is steep. After a certain level of expenditure the curve flattens and approaches the asymptotic probability as the dollar amount becomes infinitely large. The relationship between dollars, probability of successful completion P (s), and limiting probability (k) is shown in Figure 4. The relationship can be expressed as follows:

$$P\ (s) = k\ (1 - e^{-c\$}),\ ^{1}\ \ldots\ldots\ldots\ldots\ldots\ 6$$

where,

[1] Ideally, P (s) = $K_1 - k_2\, e^{-c\$}$. For our purpose, when \$ = 0, the intercept is zero. Letting P (s) = 0, when \$ = 0, it can be shown $k_1 = k_2$.

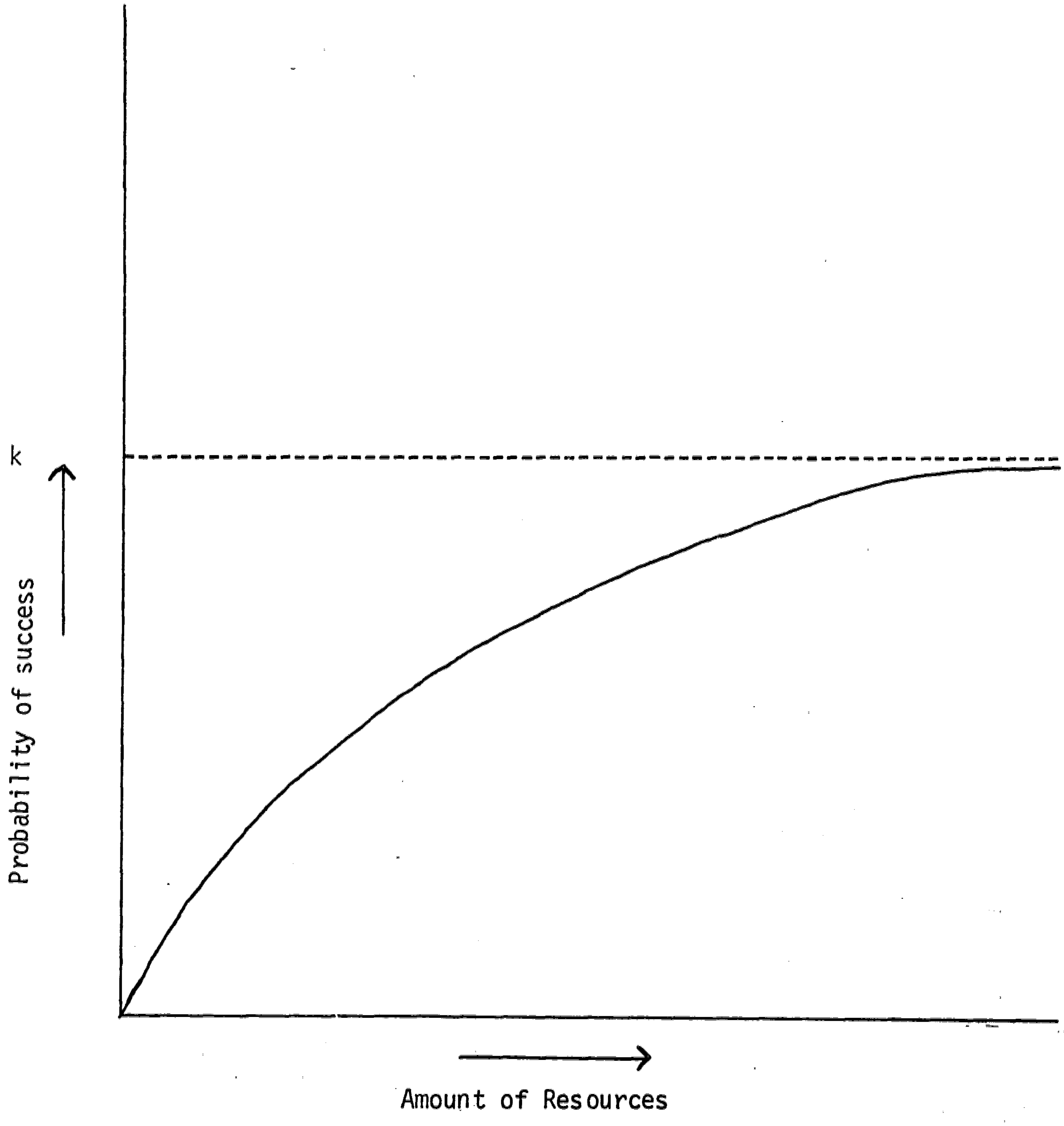


Figure 4. Depicting the relationship between amount of resources and the probability of successful project completion.

P (s) = probability of successful project completion,

k = limiting probability,

e = base of natural logs, 2.71828 (approx.)

\$ = dollars allocated

c = sensitivity value

The sensitivity value, c, is related to the rate of change in probability value as the dollars expenditure change. In other words, c is an indicator of the slope of the curve in Figure 4. Substituting expression 6 in equation 5 the following equation is obtained:

$$E\ (R) = (r + L)\ k\ (1 - e^{-c\$}) - L \quad . \ . \ . \ . \ . \ . \ . \ . \ 7$$

Simplification of expression 7 gives the following:

$$E\ (R) = (r + L)\ k - (r + L)\ k\ e^{-c\$} - L \quad . \ . \ . \ . \ . \ 8$$

which can be rewritten as follows:

$$E\ (R) = a - y - b, \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ 9$$

where,

$$a = (r + L)\ k$$

$$y - (r + L)\ k\ e^{-c\$}, \text{ and}$$

$$b = L.$$

It can be observed that the terms x and z are constants and the term y is a variable, since only y is a function of \$. As the y can be varied as the function of resources allocated to the project, the y term is the only one which can be manipulated. Since the y term carries a negative sign which indicates a substractive operation, the y term must be minimum in order to achieve maximum expected reward. The minimization of the y term would yield maximum expected reward. Hence, the project selection process forms a minimization problem, i.e., in order to maximize E (R), it is necessary to minimize $(r + L)\ \overline{ke^{-c\$}}$.

So far we are concerned with only one project. However, the main concern is to select a subset of projects that maximize the total reward over all projects. The above mentioned model can easily be extended to accommodate more than one project. When there are N projects, equation 8 becomes,

$$\sum_{j=1}^{N} E\ (R)_j = \sum_{j=1}^{N} (r_j + L_j)\ k_j - \sum_{j=1}^{N} (r_j + L_j)\ k_j\ e^{-c_j \$_j} = \sum_{j=1}^{N} L_j \quad . \ . \ 10$$

where the subscript j refers to $j^{th}$ project, and other symbols are as defined earlier.

Expression 10 can be rewritten for simplification purposes as

$$\Sigma E\ (R) = A - Y - B \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ 11$$

where,

$$A = \sum_j (r_j + L_j)\ k_j,$$

$$Y = \sum_j (r_j + L_j)\ k_j\ e^{-c_j \$_j}, \text{ and}$$

$$B = \sum_j L_j\ .$$

As with project equation 9, this can be generalized to state that in order to maximize the cumulative expected reward $\sum_{j=1}^{N} E\ (R)$, one has to minimize the Y term in equation 11.

The project selection process requires that the cumulative expected reward from the projects selected is maximum. In order to increase the expected reward, the B term in expression 11 should be minimized. Increasing the probability level of successful project completion will increase the expected reward. It is assumed that the probability level is a function of the amount of dollars expended. However, the total amount of dollars required for project expenditure should not exceed the actual budget level. Thus a constraint is imposed on the decision process. Mathematically the constraint can be shown as follows:

$$\sum_j \$_j = M,$$

where

$\$_j$ = amount of money allocated to the project j, and

M = total budget.

It can be seen that the amount allocated to projects actually determines the projects selected, since a zero allocation indicates that no effort is expended on that project.

The problem of project selection process can be summarized as follows:

$$\text{Minimize } Y = \sum_j (r_j + L_j)\ k_j\ e^{-c_j \$_j}$$

subject to $\sum_j \$_j = M$, and $\$_j \geq 0$.

Since the assumption $r_j = L_j$, the problem becomes one of minimizing

$$Y = \sum_{j=1}^{N} 2\, r_j\, k_j\, e^{-c_j \$_j}$$

subject to $\sum_j \$_j = M$, and $\$_j \geq 0$.

The problem can be solved using the method explained by Charnes and Stedry (1964). The algorithm for solving the problem is given in Appendix B. Computerization of the algorithm is given in Appendix C.

## Estimation of Variable Values

The project selection model contains six variables: (1) return value $(r)_j$ from the j project $j = 1,2, \ldots N$; (2) loss value $(L)_j$; (3) probability $P_j(s)$ of successful completion of the project given the expenditure of dollars; (4) limiting probability $k_j$; (5) sensitivity value $c_j$; and (6) total monetary resources available M. Procedures are given below which can be used to estimate the variable values.

The return value refers to the utility score. A project's utility score is related to its contribution to model simulation and the sequential ordering with which information is generated in model construction. The projects which yield the most important information in building models would have the highest utility value. The assignment of utility value also depends upon whether other projects have to wait for the completion of the project on hand. If so, the project whose successful completion will initiate other projects would receive higher utility value than other dependent projects. Thus the utility value refers directly to the informational contribution that a project makes in constructing models.

As discussed earlier in the development of the project selection model, the loss is equal to the return value when the project is not completed successfully. In other words, loss reflects unrealized return.

The probability of the successful completion of a project is dependent on the amount of money expended on the project. It should be noted that it is the successful completion of the project that is important in this conception. Success is defined as the securing of the information of the desired power, precision, and reliability to load the meta model. Power bears upon the notion of how much control over the information the investigation provides. Weak information may do no more than suggest a way of altering events without stipulating the nature of the outcome, while strong information may include the necessary and sufficient conditions for an event, stipulated in precisely measured terms. Precision refers to the exactness with which the projected outcomes are related to real outcomes, and also to the accuracy of the information, the quality of measurements in which the description of the information is stated. Reliability of the proposal has to do with the frequency with which discrepancies in information occur.

Determination of the limiting probability (k) depends on the project specifications and more specifically on the quality of the information to be gathered. As mentioned earlier, the level of information gathering ranges from soft information to hard information. Soft information is easier to gather according to project specification than is hard information. As such, the level of limiting probability of success changes as the level of information shifts. For example, if a project requires soft information the k value would be high. On the other hand, the k value would be lower if the project specification requires hard information. There is a trade-off function between the level of information and the limiting probability. Thus, the project which is to yield very broad, general, and occasional information is assumed to have a higher asymptotic probability of successful completion than a project which is required to yield very precise, narrow, and reliable information.

For example, a project which requires the use of existing records and documents can generally be considered a low risk project with a consequent high value implying that the required information can be gathered with a high probability of success given expenditure of enough resources. The high risk project will have a low k value, implying that it is less likely to get the required information even with large expenditures of resources.

Estimation of the probability of success requires an act of subjective judgment, with either a panel of experts or a single individual making the decision. It is quite advantageous to estimate the limiting probability of the project completion first. Depending upon the limiting probability value, k, other probability values can be estimated.

The limiting probability value can be obtained by asking the following question for each of the **m** projects:

> What is the limiting probability of success that the given project can reach if the amount of money expended on the project is infinitely increased?

If a panel of judges is used, the average value across the members of the panel would constitute the k value.

The probability of successful completion of a project depends on the amount of resources expended on the project. The relationship between the resources and probability determines the slope or sensitivity value of c in the project selection model. The c value can be estimated using the following procedure.

The total resources, M, which are available for R & D purposes is known. The total resources can be divided into arbitrary levels, say, tens of thousands of dollars. For each arbitrary funding level an estimate of the probability of successful completion of the project is made assuming that funding level. If a panel of experts is used, the average across the members could serve as the probability level for a given level of funding. The following question can be asked to get the expert opinion:

> What is the probability that the given projects will be successfully completed if $\$_i$ dollars are expended on the project?

Here, $\$_i$ is a specified funding level. For purposes of estimation, $i \geq 3$. Analytically, the value of c for a project is as follows:

$$-\ln \left(1 - \frac{P_i}{k}\right) = c\$_i$$

where

$k$ = limiting probability value,

$P_i$ = probability estimate at the $i^{th}$ arbitrary funding levels,

$c$ = sensitivity or slope, and

$\$_i$ = dollar value of the $i^{th}$ funding levels.

For purposes of estimation, the above equation can be stated in a linear regression form as

$$Z = a + c\$ + \xi \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 13$$

where

$Z = -\ln \left(1 - \frac{P_i}{k}\right)$, dependent variable

$a$ = intercept,

$c$ = slope,

$\$$ = independent variable, and

$\xi$ = random variable representing subjective error.

As we know that when no money is spent ($\$ = 0$) the probability is zero ($P = 0$), the intercept is zero ($a = 0$). By using the linear regression techniques and setting $a = 0$, the c (slope) can be estimated.

## Implications of the Project Selection Model

The meta model guides the generation of projects which provides the information needed to load the system model. As such, all the projects so generated are necessary for building dynamic models of the real systems of interest to the R & D center. Although the utility level may vary from one project to another, essentially all projects contribute to model building activities and thus have utility values. Although all projects are essential for model building, all projects may not be carried out because of limited resources. As a consequence, only a subset of the projects may be selected.

The projects which are not selected by the project selection process contribute loss to model building activities. That is, the projects which are ignored because of budgetary limitation represent a loss in terms of unrealized potential. The project selection model takes this loss into consideration. When a project is not selected, no money is spent on the project. If no money is expended on the project the value of \$ in equation 8 is zero. If we let \$ = 0, the expected reward is equal to -L. As previously stated, the loss (L) is equal to return (r), indicating the loss due to a non-selected project is equal to its utility value. Thus, if a project is not selected, i.e., if no money is expended on the project it contributes a loss to the expected reward for all projects generated.

Another interesting thing to observe in the model is the effect of change in the parameter values. For example, if we hold the return (r) and sensitivity ($c_j$) constant across a set of projects, $j = 1,2, \ldots m$ and vary only $k_j$, i.e., if all projects have the same return and sensitivity but different limiting probability, the limiting probability will determine the selection of projects. That is, the project which has the highest $k_j$ would be selected first, and the project with the lowest $k_j$ would be selected last. As the return is constant for all projects, all projects would contribute equally upon completion. However, the probability of completion may differ from one project to another. As $P_j$ is a function of $k_j$ and $\$_j$, with $c_j$ being constant across all projects, for a given funding level (\$) the probability of a project with a higher $k_j$ would be greater than that of a project with a lower $k_j$. As the $P_j$ increases, so also does the expected return. The higher the expected return, the higher the expected reward. Consequently, the project with a high $k_j$ would be chosen first and the project with the lowest $k_j$ last. The implication is that <u>when the utility score and sensitivity level are equal across all projects, the low-risk projects (high $k_j$) will be funded first and high risk projects (low $k_j$) will be funded last.</u>

When the $r_j$ and $k_j$ are constant across all projects, the variable $c_j$ determines the project funding level. The project with a steep $c_j$ will reach its highest $P_j$ level sooner than a project where $c_j < c_j$. Consequently, the project with a high $c_j$ will be selected first. The project with a high $c_j$ can reach the probability peak at lower funding level than a project with a flatter probability curve. Therefore, the projects whose sensitivity is high will be funded at lower levels than the projects with low sensitivity levels which require more funding to reach a probability of success that will result in a maximum expected total reward.

Utility value also determines the priority level of the projects. If the $c_j$ and $k_j$ are constant across all projects and if only the $r_j$ differs from one project to another, the project with the lowest utility score would hold the lowest rank in the priority rank order. As $P_j$ is a function of $k_j$, $c_j$ and $\$_j$, and $k_j$ and $c_j$ are assumed to be constant, for a given resource level ($) the $P_j$ are identical across all projects. Hence, as the expected return is a function of $r_j$ and $P_j$, and as the $P_j$ is identical across all projects, the projects with the highest $r_j$ value will have the highest expected return value, and the project with the lowest $r_j$ will have the lowest expected return value. Therefore, the project with the highest utility score will be given maximum priority (selected first) and the lowest utility score project will hold lowest priority.

When two or more model parameters are free to vary, as is generally the case in a practical application, the results are not so obvious, since complex interactions tend to obscure simple parameter effects.

## APPLICATION OF THE PLANNING SYSTEM

This part of the study presents an application of the procedure developed in the preceding sections to a specific site. The Center for Occupational Education, North Carolina State University, was chosen for this purpose.

The salient objectives in this section are:

1. Delimitation of the mission, goals, and objectives of the Center.

2. Formation of guidelines for the generation of projects using the procedures outlined in the earlier section.

3. Development of a computerized procedure for the selection of projects.

### Mission, Goals, and Objectives of the Center

As a result of conferences held with the director of the Center, the following mission, goals, and objectives are proposed for the Center of Occupational Education. It should be understood that the mission, goals, and objectives being presented are merely for heuristic purposes and the statements do not necessarily reflect the mission, goals, and objectives of the Center for Occupational Education as they presently exist.

#### Mission

The mission of the Center is:

> To influence the process of occupational education at the state and/or regional level through the development of dynamic models for the design, implementation, and evaluation of delivery systems of occupational education.

One can find two key terms in the mission statement. They are "influence" and "the development of dynamic models." The first key word, "influence," deals with the process, whereas the second term deals with the products, namely models. The assumption is that the Center can exert its influence only through enhancing explanations of occupational educational delivery systems and that explanation is possible only through models.

Further, it was gathered from the Director that the Center is concerned with the post-secondary delivery system and the middle-grade delivery system. Based on this rationale the goals of the Center have been stated as follows:

Objectives

1. To develop models for design and implementation of vocational education delivery systems at the post-secondary level.

2. To disseminate the models to the state and regional agencies.

3. To develop models for design and implementation of vocational education delivery systems at the middle-grade level.

4. To disseminate the models to the state and regional agencies.

It follows from the stated objectives that the Center should be concerned with the construction of models of certain domain systems, namely the post-secondary and middle-grade delivery systems. A model as herein used is a set of interrelated variables whose purpose is to explain the description of a system that exists in a real world. It is only through the power of the model that relevant activities of the domain system are identified, explained, and ultimately controlled through appropriate intervention.

Using a model one can look at all the relevant variables operating in the real system. A model, thus, forms a framework for processing experience pertaining to the system. As such, the model helps to interpret experience and permits prediction of system activities without indulgence in the real system. The model as an orderer of perceptions identifies all the important variables in the system. As the model allows prediction, it also provides a means of identifying potential problem areas in the system, for a model is a ways and means of ordering the phenomena; it serves to generate strategies to tackle the problems when they arise. The model suggests points of intervention and opportune times and places and thereby serves as a guideline to manipulate important variables. It provides means of changing the appropriate variables so as to obtain desired results. When necessary, it aids in redesigning or restructuring the system. Thus a model forms a theoretical basis for an orderly way of understanding and evaluating the system.

A dynamic model is a special type of model in which the passage of time is of critical importance. For example, a dynamic model helps to identify the state of the system at a given point in time. Comparison of system states at different points in time permits formulation of the dynamics of system behavior. Thus a dynamic model helps to forecast certain phenomena in temporal dimension. Computerization of a dynamic model results in a simulation model. The computerization provides for the rapid bookkeeping activities required to model system behavior over time. Simulation models are useful in understanding, predicting and controlling the systems involved in the vocational process. As such, models of these systems are the means whereby the Center can influence the process, and are in no sense to be interpreted as ends in themselves.

## Planning System for the Center for Occupational Education

The planning system developed for the Center is shown in Figure 5. The operation of the planning system consists of three basic phases.

Phase 1 consists of three parts. The first part concerns delimiting and delineating the Center's goal areas. The second part involves construction of a static model of each system corresponding to a Center goal area. The static models serve as guidelines to carry out the operations in Part 3. In Part 3 a system analysis is carried out for each system domain.

The results of the analysis of the system is a description and assessment of the system in terms of system environment, components, resources, and management. It provides information about the internal structure and mechanism of the system. An assessment of the system provides knowledge about the performance of the system, indicating the quality and quantity of the system performance.

Phase 2 involves an evaluation of the system under study. During this phase, the system is examined to determine whether it is operating at the desired level of performance. In this phase, experience supplied by the assessment part of the first step and establishment of the criterion level are used to evaluate the system performance. If the system performance is at par, that is, if the system is producing the desired behavior, it is left alone, implying that no immediate problems exist in the system. If the system performance is not at the desired level, Phase 3 is initiated.

In Phase 3, the planning system developed in Part 1 is incorporated, i.e., the meta model and the project selection model are implemented in this phase. It should be noted that Phases 1 and 2 are completed before initiating Phase 3. The system description of Phase 1 and the evaluation of Phase 2 help to delineate the problem areas. Computer simulation procedure helps to seek alternate solutions to the problems delineated. The basic ingredient of the simulation process is a dynamic model of the system under consideration. The simulation model provides the explanatory power needed to explain the phenomena observed in Phase 1. Thus, in Phase 3 models are constructed which serve as the theory directing and shaping future experience regarding vocational delivery systems.

Information that is obtained from the system analysis (Phase 1) can be used to construct a flow-chart of the system under study. Given GPSS as the syntax, the flow-chart represents a dynamic model of the system. Experience gleaned from the system analysis can provide answers to questions stated in the general information section of the meta model. In this manner, a flow-chart which forms the basis to build a sophisticated model of the system is constructed.

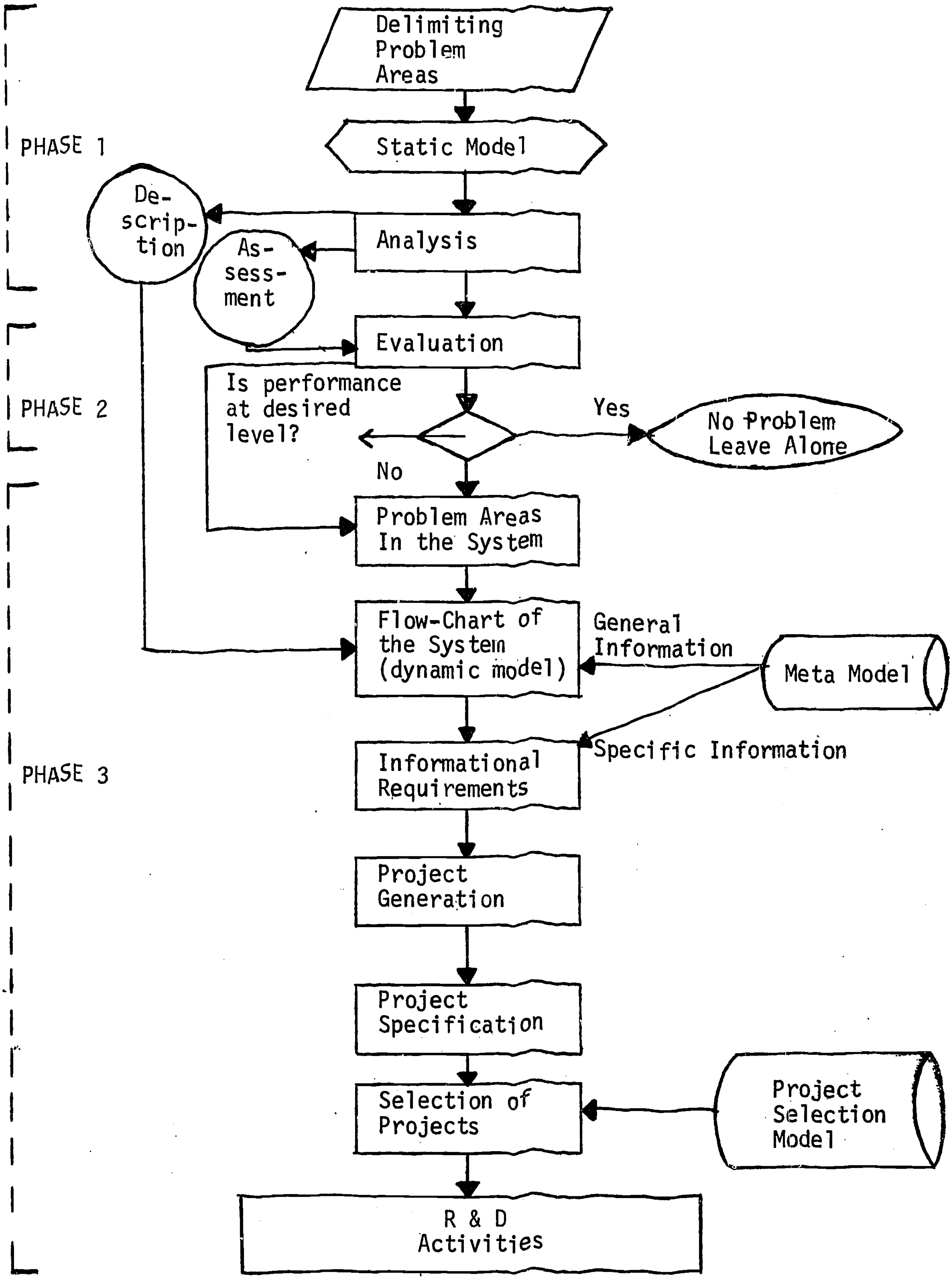


Figure 5. Schematic representation of the Center planning system.

The flow-chart once formulated dictates the information required to load the model for simulation. Answers to specific questions in the meta model, i.e., loading the GPSS blocks, would result in a specific simulation model. As the flow-chart provides direction in the information-gathering process, the specific questions stated in the meta model dictate the informational content. The information requirements suitably partitioned generate projects. Thus, the simulation model so constructed forms the basis for research projects. However, available resources can not generally support all the projects. In this connection, the project selection model is used to select those projects that will result in a maximum overall reward.

The project selection model can aid in selecting projects so as to optimize the expected reward for the available resources. The reward, in this connection, is analogous to the profit that incurs as a result of the allocation of resources to specific projects.

The above planning system is illustrated in the following section.

## An Illustration of the Application of the Planning System

One of the proposed goal areas concerns the building of a model of the post-secondary delivery system. Using a static model of the delivery system as a basis of generating a description, let us assume that a system analysis had been performed. The analysis helps to describe the system and to assess its current performance. Suppose the evaluation of the system reveals that the performance has to be improved.

The problem is to design a post-secondary delivery system to operate at the desired performance level. Various design alterations can be created and evaluated by simulation techniques. The process of simulation allows the manipulation of variables that would effect the most secondary delivery system outputs. By making necessary changes in the variables, various design alternatives can be obtained and evaluated. The basic necessity for a simulation process is a dynamic model of the system. Thus, in order to approach the post-secondary area in a creative manner, it is required to construct a dynamic model of the post-secondary system.

The meta model furnishes the guidance for building a dynamic model of the system. Loading the meta model, i.e., supplying appropriate answers to the questions in the meta model, would result in a specific model of the system. The activities of gathering information so as to supply answers to the questions form research activities, which in turn formulate projects. The projects could conceivably be classified under one of five subprogram areas; namely, planning and evaluation; management and decision-making; recruitment, classification, and counseling; curriculum and instruction; and placement and follow-up (Coster, 1970). Each project would provide information in one of five areas.

After projects are generated specifications about the level and quality of informational requirements should be formulated. The information level may vary from <u>soft</u> to <u>hard</u>. Soft information content projects are low-risk projects <u>and the projects</u> which seek information at very precise and specific levels are high-risk projects. The Center may have resources to support only a limited number of projects. The project selection model is thus an aid in decision-making in that it provides an explicit scheme for evaluating the effects of various decision alteratives.

Let us assume that three projects were identified as necessary to supply relevant information to construct a simulation model of a post-secondary delivery system. Total resources (M) can stand for technical personnel, money, or some other kind. It is necessary that all types of resources be pooled using a common scale denominator. For the purpose at hand, dollars appear to be the most convenient resources scale units. Let us assume the Center has $100,000 for R & D activities. Application of the project selection model requires an estimate of $r_j$, $k_j$, and $c_j$ for each project. These variable values can be estimated using the techniques identified in Part 1.

One or more judges can be used to estimate the parameter values. In this context, what Bloom (1968) said may be worth mentioning. He stated "a theory must be formulated by one person, preferably the leader of an R & D center, and then altered as the result of heated debate by a group."

Following Bloom's suggestion, one judge, preferably the director of the Center, should estimate the variable values and, from his experience, assign utility values to the three projects. Let us assume that he assigned the utility values of 50, 100, and 300, using some arbitrary units of measurement, to the first, second and third projects respectively. Organizational goals and expert judgment and experience govern the assignment of the utility values to the projects.

Organizational facilities in terms of technical personnel, potentialities and capabilities dictate the estimation of the $k_j$ values. For example, if the project specification requires certain technical personnel to carry out the project and if the organization lacks the facility, then the $k_j$ value is low, implying a high-risk project. For example, assume that all three projects are low-risk projects, implying that with sufficient resources the projects can be successfully completed. The respective limiting probabilities are .9, 1.0, and .95.

Estimation of sensitivity ($c_j$) of the projects is somewhat tricky and complex, and it requires computation. An indirect procedure to estimate the $c_j$ values can be using the linear regression method. The total resources ($100,000) can be arbitrarily broken down into several levels of funding. For a given funding level, a probability of successful completion is estimated. Assume that the total money is divided into five funding levels of \$10,000, \$20,000, \$35,000, \$60,000 and \$100,000. The probability at each funding level, as estimated by the judge, is given in Table 2.

Table 2. Probability of completion at a given level of funding.

| Funding Level | Project 1 r=50; p | k=9 z | Project 2 r=100; p | k=1.0 z | Project 3 r=300; p | k=95 z |
|---|---|---|---|---|---|---|
| \$ 10,000 | .5 | .812 | .3 | .3567 | .3 | .3298 |
| \$ 20,000 | .7 | 1.5051 | .7 | 1.204 | .5 | .7465 |
| \$ 35,000 | .82 | 2.4304 | .85 | 1.7148 | .85 | 2.2538 |
| \$ 60,000 | .85 | 2.882 | .9 | 2.3026 | .86 | 2.3538 |
| \$100,000 | .87 | 3.4112 | .925 | 2.5903 | .87 | 2.3645 |

The estimation of $c_j$ can be formed as a linear regression problem as follows:

$$-\ln (1 - \frac{P_{ji}}{K_j} = c_j \$_{ji},$$

where the subscript j refers to the $j^{th}$ project and the subscript i refers to the $i^{th}$ funding level. If we let

$$z_{ji} = -\ln (1 - \frac{P_{ji}}{k_u})$$

the regression model is as follows:

$$z_{ji} = c_j \$_{ji}.$$

The respective $z_{ji}$ values are given in Table 3. The above regression problem can be solved as follows:

$$c_j = \frac{\underset{x=1}{} \$_{ji} Z_{ji}}{\sum_{i=1} \$^2_{ji}}$$

Using the above equation, the $c_j$ were computed and they are given in Table 3. It can be observed that $z_{ji}$ is a function of $c_j$ and $\$_{ji}$. As such,

Table 3. Effects of changing measuring units of $\$_{ij}$ on $c_j$.

| Total Money | M = 100,000 | M = 100 Scale Unit: 1,000 | M = 10 Scale Unit: 10,000 | M = 1 Scale Unit: 100,000 |
|---|---|---|---|---|
| Funding Level | | | | |
| | 10,000 | 10.0 | 1.0 | .1 |
| | 20,000 | 20.0 | 2.0 | .2 |
| | 35,000 | 35.0 | 3.5 | .35 |
| | 60,000 | 65.0 | 6.5 | .65 |
| | 100,000 | 100.0 | 10.0 | 1.0 |
| $C_1$ | .00004159 | .04159 | .4159 | 4.159 |
| $C_2$ | .00003164 | .03164 | .3164 | 3.164 |
| $C_3$ | .00003101 | .03101 | .3101 | 3.101 |

when the $\$_{ji}$ is large the $c_j$ tends to be small, as $z_{ji}$ is limited by the restriction that $(P_{ji}, k_j) \leq 1$. If $\$_{ji}$ is very high, the computation of $c_j$ may involve significant rounding errors. In order to minimize the rounding errors, the unit of measurement of $\$_{ji}$ can be altered. Examples of changing the units of measurements and their effects on the $c_j$ values are given in Table 4. It should be noted that the change in $\$_{ji}$ scale units does not affect the $P_{ji}$, but affects the $c_j$ proportionately.

Another method of estimating the $c_j$ values is based on the method used in PERT technique in estimating the completion time. Similar to estimating the optimistic and pessimistic time of completing a project in PERT, a probability level for the "optomistic" and "pessimistic" fundings can be obtained from the expert judgment. The third probability value for the "realistic" funding level somewhere between the "optimistic" and "pessimistic" levels can be obtained. The linear regression method can then be applied to compute the $c_j$ value.

There may be occasions where it would be difficult to estimate the probability of success at various funding levels. In situations like this, a one-point estimation procedure can be followed. The one-point estimation essentially involves estimating the probability value at only one funding level. When the one-point procedure is used the $c_j$ can be computed as follows:

$$c_j = \frac{-\ln\left(1 - \frac{P_i}{k_j}\right)}{\$_i}$$

$\$_i$ = funding level,

$P_i$ = probability of success at the funding level $\$_i$, and

$k_j$ = limiting probability of the $j^{th}$ project.

The result of the computerized procedure of the project selection model using M = 1 and the associated c values is given in Table 4.

Table 4. Allocation of resources to three projects when total resource, M = 1.

| Project Number | r | k | c | $ | P | Cumulative Resource | Cumulative Expected Reward |
|---|---|---|---|---|---|---|---|
| 3 | 300 | .95 | 4.159 | .622919 | .812 | .622919 | 37.40 |
| 2 | 100 | 1.0 | 3.164 | .285861 | .595 | .90878 | 156.45 |
| 1 | 50 | .90 | 3.101 | .091222 | .284 | 1.0000 | 184.87 |

Table 4 indicates that all the three projects were selected in that a non-zero amount of resources was allocated to each. When project Number 3 is allocated .623 units of resources, which is equivalent to $62,291.90, the probability of successful completion is more than .81. For the allocation of $28,586.10 on project Number 2, the probability of successful project completion is .595. Similarly, the probability on project Number 1 is .28 when .091 unit of resources is allocated. The cumulative reward from the three projects is 184.87 and represents the maximum amount possible for any allocation of resources to the three projects. The result of the project selection method implies that in order to obtain maximum reward for the available resources, the resources should be distributed as indicated in Table 5. As such, it is beneficial to select all the three projects at the current monetary constraint. Again, it should be emphasized that the cumulative reward of 184.87 is all that can be expected for the available resources expended.

It is emphasized that the project selection model does not replace the decision-maker. The project selection does not make the final decisions. The project selection model simply supplies management information to the decision-maker. It provides guidelines to make decisions. The final decisions always rest with the authoritative manager.

The project selection model gives the manager a means to explore alternative ways of allocating resources to projects. It facilitates the manager's decision-making. It is a tool by which the manager can explore possibilities of adding projects with added resources. The project selection model is the framework for decision-making. It is a method for objectively estimating the payoffs for the resources expended. The manager always has the privilege of overriding the results from the computerized project selection procedure.

The effect of changes on variable values alters the amount of resources ($) allocated to each project. In order to demonstrate such effects, the project selection model has been applied to ten projects with several arbitrary combinations of variable values. The results are shown in the following section.

Table 5. Resource allocation when k and r are fixed, M = 5

| | c | r | k | P | $ | Σ$ | ΣE(R) | Selection Order |
|---|---|---|---|---|---|---|---|---|
| KR1 | 15 | 100 | .7 | .68 | .248 | .248 | -863 | 1 |
| KR2 | 10 | 100 | .7 | .674 | .33 | .87 | -593 | 3 |
| KR3 | 5 | 100 | .7 | .649 | .524 | 1.8 | -330 | 5 |
| KR4 | 2 | 100 | .7 | .573 | .852 | 3.35 | -92 | 7 |
| KR5 | 15 | 100 | .7 | .19 | .64 | 5.0 | 35.0 | 9 |
| KR6 | 1 | 100 | .7 | .44 | 1.01 | 4.36 | -31 | 8 |
| KR7 | 3 | 100 | .7 | .615 | .703 | 2.50 | -207 | 6 |
| KR8 | 7.5 | 100 | .7 | .67 | .40 | 1.27 | -459 | 4 |
| KR9 | 12.0 | 100 | .7 | .68 | .291 | .539 | -727 | 2 |
| KR10 | .2 | 100 | .7 | - | - | - | - | - |

## Effects of Changes on Variable Values

A set of ten projects was used to demonstrate the effects of altering the values of the variables. The variable values were altered in one of four ways: (1) the $r_j$ and $k_j$ were held constant across ten projects and the $c_j$ was varied from one project to another; (2) the $r_j$ and $c_j$ were constant and the $k_j$ was varied; (3) the $c_j$ and $k_j$ were held constant and $r_j$ was altered one project to another; and (4) all three variables were let free. The results are given in Tables 5-8.

The results indicate that the parameter values change the resource allocation mix. When the $k_j$ and $r_j$ were held constant across all ten projects and only the $c_j$ was varied, the result shown in Table 5 indicates that the selection order of projects is directly dependent on the $c_j$ value. The project with the highest $c_j$, namely project code KR1, was the first project allocated resources, while the project with the least $c_j$ (KR10) was not selected at all. The selection process also shows that as the

Table 6. Resource allocation when only the k varied, M = 50

| | c | r | k | P | $ | Σ$ | ΣE(R) | Selection Order |
|---|---|---|---|---|---|---|---|---|
| CR1 | .5 | 100 | 1 | .96 | 6.53 | 6.53 | -807.6 | 1 |
| CR2 | .5 | 100 | .95 | .91 | 6.43 | 12.95 | -625.3 | 2 |
| CR3 | .5 | 100 | .50 | .46 | 5.14 | 35.5 | -135.9 | 6 |
| CR4 | .5 | 100 | .25 | .21 | 3.76 | 48.08 | 31.2 | 9 |
| CR5 | .5 | 100 | .1 | .062 | 1.92 | 50.0 | 43.6 | 10 |
| CR6 | .5 | 100 | .3 | .26 | 4.12 | 44.3 | - 11.1 | 8 |
| CR7 | .5 | 100 | .4 | .362 | 4.70 | 40.2 | - 63.5 | 7 |
| CR8 | .5 | 100 | .6 | .56 | 5.51 | 30.4 | -228.2 | 5 |
| CR9 | .5 | 100 | .7 | .66 | 5.82 | 24.85 | -340.6 | 4 |
| CR10 | .5 | 100 | .8 | .76 | 6.08 | 19.04 | -472.9 | 3 |

Table Resource allocation when c and k are fixed, M = 5

| | c | r | k | P | $ | Σ$ | ΣE(R) | Selection Order |
|---|---|---|---|---|---|---|---|---|
| CK1 | .6 | 950 | .95 | .68 | 2.12 | 5.0 | 627 | 2 |
| CK2 | .6 | 200 | .95 | - | - | - | - | - |
| CK3 | .6 | 50 | .95 | - | - | - | - | - |
| CK4 | .6 | 1500 | .95 | .78 | 2.88 | 2.88 | -671.0 | 1 |
| CK5 | .6 | 25 | .95 | - | - | - | - | - |
| CK6 | .6 | 100 | .95 | - | - | - | - | - |
| CK7 | .6 | 100 | .95 | - | - | - | - | - |
| CK8 | .6 | 75 | .95 | - | - | - | - | - |
| CK9 | .6 | 10 | .95 | - | - | - | - | - |
| CK10 | .6 | 5 | .95 | - | - | - | - | - |

Table 8. Resource allocation when all variables varied, M = 5

| | c | r | k | P | \$ | $\Sigma$\$ | $\Sigma$E(R) | Selection Order |
|---|---|---|---|---|---|---|---|---|
| 1 | .2 | 2000 | 1. | .45 | 2.96 | 4.88 | 3656.7 | 4 |
| 2 | .5 | 200 | .7 | - | - | - | - | - |
| 3 | .35 | 1000 | .5 | .24 | .77 | 1.92 | 1871 | 3 |
| 4 | .6 | 25 | .9 | - | - | - | - | - |
| 5 | 1 | 500 | .5 | .06 | .121 | 5.0 | 3714 | 5 |
| 6 | 5 | 1000 | .95 | .91 | .61 | 1.1 | 1392.0 | 2 |
| 7 | 7 | 100 | .2 | - | - | - | - | - |
| 8 | 2 | 50 | .5 | - | - | - | - | - |
| 9 | 10 | 5000 | 1.0 | .996 | .54 | .54 | -419.3 | 1 |
| 10 | 1 | 500 | .3 | - | - | - | - | - |

$c_j$ increases, the fewer resources are allocated. For example, the project with the $c_j$ value of 15.0 was allocated an amount of \$.248, whereas the project with the $c_j$ value of .5 was allocated \$1.01. Thus, the relationship between the $c_j$ and selection order is direct and the relationship between $c_j$ and $\$_j$ is inverse.

Table 6 shows the results of varying only the $k_j$ (limiting probability value) and holding other parameters constant. The selection order of the projects depends on the $k_j$ levels. Those projects with a higher $k_j$ level are selected sooner than those with a lower $k_j$. Similarly as the $k_j$ level increases more resources are allocated, thereby increasing $P_j$. Thus, there is a direct positive relationship between $k_j$, selection order, $\$_j$ and $P_j$. As the $k_j$ increases, priority level increases, more resources are allocated and the probability of success improves. It can be also noted in Table 6 that the resources are allocated to projects in such a way that the probability of success approaches the respective k values.

Table 7 shows the results when the $c_j$ and $k_j$ are constant and $r_j$ varied. Interestingly enough, only two projects out of ten were selected. The project with the highest $r_j$ was selected first and the project with the second highest $r_j$ was selected next. Allocation of all resources between the two projects which have very high $r_j$ values indicates that when the c values and k values are constant across all projects, the projects with relatively very high utility values would contribute more to the reward.

Ten projects were compiled such that they simulated a real situation. All three parameter values were varied on the ten projects. The result of the project selection process is shown in Table 8. Unlike previous situations when only one variable was varied at a time, complexity makes it difficult to infer the selection criterion. As all three variables were varied it is the complex interaction between variables that obscures direct interpretation of the result. Five out of ten projects were allocated resources. It appears that the project with high values on all three variables (project 9) was selected first. Its probability of success (.996) is very close to its k value (1.0).

It should be remembered that in the above examples total available resources were set arbitrarily to M = 5 (Tables, 5, 7, 8) or M = 50 (Table 6). They were set so as to demonstrate the effects of the changing values. It can also be observed in all examples (Tables 5-8) that as more projects are added to the selection list the cumulative expected reward increases. When only one project was selected the cumulative expected reward is negative, implying that if no additional resources were allotted to projects, those projects not selected would contribute a loss to the cumulative expected reward. The selection procedure operates in such a way that addition of projects to the selection list decreases the loss. From the given list of projects the procedure selects those projects and allocates resources so as to result in the maximum expected reward.

## Practical Implication of the Project Selection Model

The project selection model can serve as a tool in decision-making. The decision-maker can experiment with the resource allocation and selection process by varying the parameter values in the selection model. For example, the decision-maker can simulate with actual projects the allocation process for differen[illegible] of limiting probability and sensitivity. The project selection r[illegible]es management with the capability of evaluating alternative [illegible] allocation mixes depending upon designated parameter values.

The educational centers are supported by the U. S. Office of Education. The number of projects that a center can undertake depends on the size of the grant by the USOE which may vary from time to time. Whenever the decision-maker suspects that the size of the grant may be increased or decreased, he has to make decisions on what projects to undertake and what not to undertake. The project selection model can solve some of the decision-maker's worries. The decision-maker can play with the model by changing the total money level, M. He can evaluate the project potentials at different total available resources. For different M levels, the allocation mix would vary. Using the allocation mix and selection process as the guide, he can make appropriate decisions.

Another use of the project selection model is to determine the mix of projects. For example, there are five projects and the decision-maker wants to determine if combining two projects of the five into one project would be more beneficial than five separate projects. The project selection model can be used to determine the effects of combining projects on reward. First, the five projects can be inputted in the computerized procedure and the cumulative expected reward can be obtained. Then the four projects (three old projects and one new project which is the combination of two old projects) can be inputted in the procedure and another cumulative expected reward can be obtained. Comparison of the rewards would indicate if combining two projects into one new project increases the expected reward. Accordingly the decision can be made as to whether to combine or not. It should be remembered that the M value is constant, and the new project has its own utility, sensitivity, and limiting probability values.

## SUMMARY AND CONCLUSIONS

Educational R & D centers are presently under criticism that their activities offer a mix of research conclusions which could not be readily matched or intermingled to produce a satisfactory solution to problems. It has been suggested that the efficiency of the centers can be greatly improved through a unified, integrated planning R & D system. The present study was addressed to the development of such an overall planning system.

The planning system consists of (1) a procedure to systematize the formulation of projects and (2) a project selection model to optimize the expected returns of R & D efforts within resources constraints.

The study is divided into two parts. A general scheme of an R & D planning system has been developed in the first part with formulation of projects based on the notion of a meta model, which is a plan that could assist investigators in model construction. The General Purpose Simulation System (GPSS) forms the base for the development of a preliminary meta model based on the modular concept.

Information gathering activities needed to load the GPSS model constitute research and development projects. Following the procedure, a greater number of projects may be generated than the available resources can accommodate. Hence, a project selection model has been proposed which can be used to select projects so as to maximize the cumulative expected reward within the available resources.

The feasibility of applying the R & D planning system in a real setting is investigated in the second part of the study. A specific planning system that can be adopted for the Center for Occupational Education is described, which is composed of three phases: (1) system analysis, (2) system evaluation, and (3) project planning phase. The third phase incorporates the R & D planning system developed in the first par

Procedures of estimating variables are shown and examples given. Variable values are arbitrarily changed to demonstrate the effect of changes on the variables on project selection decision-making. The project selection model is computerized and the program presented in the appendices.

It is shown that the low-risk projects would be selected when the utility and sensitivity values are identical across all projects. When the sensitivity alone changed, the projects with low sensitivity would be allocated high funding levels. When only the utility value changes, the projects with high utility values would be selected before those with low utility.

The major product from this study is the meta model. It contributes to the eradication of some of the problems facing the educational R & D centers. The meta model assists in bridging the communication gap that exists among the investigators from varied disciplines, as well as serving as a mediation process, i.e., it may help to reconcile differences among the investigators.

Another product from the study is the project selection model. The model provides a decision scheme to allocate the resources optimally to the projects. However, methods of estimating variable values need extensive investigation. Alternative ways of estimating the variable values and of determining their relative effectiveness need to be formulated.

The planning system that is proposed in this study appears to have intuitive validity. Implementation of the system proposed in this paper would help to alleviate the situation by leading the educational R & D centers to more rigorous project selection and concentrated and coordinated research and development activities.

The intentions of the educational R & D centers, according to Boyan and Mason (1968), require the management ability and the organizational desire to marshall extraordinary human and financial resources into well-designed sets of continuous and cumulative programmatic activities. The planning system developed in this study would seem to enforce these intentions.

## LIST OF REFERENCES


Baker, N. R. and Pound, W. H. 1964. R & D project selection: where we stand. IEEE Transaction on Engineering Management, EM-11, 124-134.

Bloom, B. S. 1968. Research and development centers: promise and fulfilment. Journal of Research and Development in Education, 1(4): 181-189.

Boyan, N. J. and Mason, W. S. 1968. Perspectives on educational R & D centers. Journal of Research and Development in Education, 1(4): 190-202.

Brandenburg, R. G. 1966. Project selection in industrial R & D problems and decision processes. In M. C. Yovits, D. M. Gilford, R. H. Wilcox, E. Staveley, and H. D. Lerner (eds.), Research Program Effectiveness. Gordon and Breach, Science Publishers, Inc., New York.

Brownell, S. M. 1968. Research and development centers and the schools: a reaction to progress reports. Journal of Research and Development in Education, 1(4):173-180.

Cetron, M. J., Martino, J. and Roepeke, L. 1967. The selection of R & D program content-survey of quantitative methods. IEEE Transaction on Engineering Management, EM-14,4-13.

Chapanis, A. 1961. Men, machines and models. American Psychologist, 16:113-131.

Charnes, A. and Stedry, A. 1964. Exploratory models in the theory of budget control. In W. W. Cooper, H. J. Leavitt, and M. W. Shelly (eds.), New Perspectives in Organizational Research. John Wiley and Sons, Inc., New York.

Chase, F. S. 1970. R & D in the remodeling of education. Phi Delta Kappan, 51(6):299-304.

Churchman, C. W. 1968. The Systems Approach. Dell Publishing Company, New York.

Coster, John K. 1970. Annual Report and Projected Activities for the Sixth Funding Period. Center for Occupational Education, North Carolina State University, Raleigh.

Dean, B. V. and Nishry, M. J. 1965. Scoring and profitability models for evaluating and selecting engineering projects. Operations Research, 13:550-568.

Kast, F. E. and Rosenzweig, J. E. 1962. Science, Technology, and Management. McGraw-Hill Book Company, Inc., New York.

Koontz, H. and O'Donnell, C. 1959. Principles of Management. McGraw-hill Book Company, Inc., New York.

Miller, D. R. 1968. A System Approach to Educational Management. OPERATION PEP, Burlington, California.

Mottley, C. M. and Newton, R. D. 1959. The selection of projects for industrial research. Operations Research, 7:740-751.

Perlman, J. 1963. Measurements of scientific research and development and related activities. In B. V. Dean (ed.), Operations Research in Research and Development. John Wiley and Sons, Inc., New York.

Pound, W. H. 1964. Research project selection: testing a model in the field. IEEE Transaction on Engineering Management, EM-11, 16-22.

Rosenfeld, J. M. and Smith, M. J. 1967. R & D planning in the decentralized organization. Research Management, 10:425-438.

Teichrew, D. and Lubin, J. F. 1966. Computer simulation--discussion of the technique and comparison of languages. Communication of the ACM, 9:723-741.

von Bertalanffy, Ludwig. 1969. General Systems Theory. Braziller, New York.

von Braun, W. 1963. Management of manned space programs. In F. E. Kast and J. E. Rosenzweig (eds.), Science, Technology, and Management. McGraw-Hill Book Company, Inc., New York.

Vovits, M. C., Gilford, D. M., Wilcox, R. H., Staveley, E., and Lerner, H. E. (eds.), Research Program Effectiveness. Gordon and Breach, Science Publishers, Inc., New York.

APPENDICES

# Appendix A

## A Description of the GPSS Blocks

## GPSS Blocks

Generate. For an input-output model, the inputs provide the impetus for system activity. Without the inputs, the system is idle. Therefore, the first activity of the system entails a generation of inputs (through-puts). This is similar to a recruitment function.

The recruits (inputs) come from various populations whose characteristics are different from one another. Each recruit carries his population characteristics. Since some populations are more attractive to the system than others, the recruits hold different priority values according to their population. Each recruit also possesses his own idiosyncratic characteristics or personal attributes.

The rate of arrival of inputs may be constant or may vary from time to time. Similarly, the interarrival rate between two transactions (recruits) may be a constant or a variable. All transactions may not come from one population. It may be necessary to allocate or restrict the sample size for a population.

The GPSS block which serves the above mentioned purposes is called the GENERATE block. The GENERATE block creates the transactions that are inputed to the system. The generation of transactions follow specified conditions (statistical distributions). Activation of this block creates transactions in a given temporal sequence (interarrival times) with certain priority attributes and characteristics. The following information is necessary to use this block.

Questions

1. What is the average time between arrival of two transactions?
2. What is the spread (similar to standard deviation of the arrival rate)?
3. Is the spread a constant or a variable? If it is a constant, what is the value? If it is a variable, can it be expressed as a mathematical function?
4. What is the time that elapses before the first recruit arrives?
5. What is the sample size? How many transactions come from this population?
6. What is the priority level to be assigned to each of the transactions being generated from that population?
7. How many parameters (attributes) are assigned to each new transaction from this population?

Assign. Each transaction can carry up to one hundred different attributes with it. It should be remembered that all attributes are numerical in value. When a transaction undergoes a process or an operation, changes may take place in one or more of its attributes. For example, a student's attributes may change as a result of a learning process or learning experience. In other words, attributes of throughputs are changed by some operation. The ASSIGN block represents the system activity that changes or modifies an attribute of a transaction. This block is the principal means of establishing the initial values of the parameter fields (attributes) of each transaction from a derived population.

Questions

1. Which of the attributes of the entering transaction is to be altered by this operation?

2. Is a value to be added to the current value, subtracted from the current value, or to replace the current value with a new value?

3. What is the function used to alter the specified parameter?

Index. The INDEX block is similar to the ASSIGN block in that it modifies the attribute value of a transaction but only to the extent that the first attribute is modified. No other attribute other than the first can be modified by the INDEX block. This block is very convenient to substitute or replace the first attribute value with some other attribute. The new value of the first parameter can be the value of another parameter or the result of a constant added to another parameter value. Thus, the new value of the first parameter, for example, can be the value of the third parameter plus a constant.

Questions

1. What is the other parameter that is used to make changes on the first parameter?

2. What is the constant which when added to the parameter value is assigned to the first parameter?

Priority. When transactions are competing for facilities or storage spaces, some transactions need to use the equipment prior to other transactions because of the priority level. Thus, some transactions may hold higher priority and some other transactions may hold low priority. The PRIORITY block is used to set the priority value for a transaction. The priority values range from 0 to 127. Higher numerical values indicate higher priorities.

Question

1. What is the priority level (number) assigned to a transaction?

Seize and Release. A facility is a resource unit which can serve only one transaction at a time. A transaction starts getting serviced by a facility when the transaction enters a SEIZE block. When a facility is serving a transaction, another transaction cannot obtain the same facility. The transaction which is currently using the facility must RELEASE the facility in order for another transaction to use it. The SEIZE block records the use of the facility by the entering transaction in such a way that the facility remains in use until the seizing transaction enters the corresponding RELEASE block. A transaction can use more than one facility at a time.

A copy of a book is an example of a facility. Only one student can use the book at a time. The book is in the student's hand as soon as he seizes it. He has to give up the book (release) in order that another student can use it.

Question

1. What is the facility that is to be used by the entering transaction? There should be a corresponding RELEASE block which will indicate the release of facility by the entering transaction which had previously seized the facility.

Preempt and Return. The PREEMPT block is used in order to free a facility which is currently in use. The transaction which enters the PREEMPT block suspends the progress of the transaction which is currently using the facility and seizes the facility. However if the facility is processing a transaction which has already preempted, the entering transaction cannot free the facility. That is, if the facility is already in the preempt condition the PREEMPT block can refuse entry to another transaction. However, there is an exception when the PREEMPT operates in the priority mode. If the PREEMPT block is operating in the priority mode, the transaction which has the higher priority value can use the facility. Thus, if the facility is already operating in the preempt condition the transaction which seeks the facility can use the facility if it holds a higher priority value than the transaction which is currently using the facility. The preempted transaction (the transaction which has lost control of the facility) always contends for the facility. As soon as the preempting transaction (which temporarily suspended the operation of the facility) releases the facility by entering the RELEASE block, the preempted transaction will seize the facility. The preempted transaction can do one of two things during the preempt condition: (1) wait for the facility or (2) perform some other activity.

The PREEMPT block temporarily stops the progress of the transaction which is currently using the facility and permits the preempting transaction to obtain the control of the facility. The RETURN block serves the function of ending the state of preempt condition of the facility.

Questions

1. What is the facility number which is sought by the preempting transaction?

2. Does the PREEMPT block operate in priority mode?

3. Where does the preempted transaction go?

4. If the preempted transaction is to wait, which of its attributes records the waiting time?

5. Does the preempted transaction need to contend for the facility?

Enter and Leave. A storage is one of the resources available to the system. A storage can serve more than one facility at a time. The ENTER block records the usage of a storage by a transaction. By entering the ENTER block a transaction can obtain the services of the storage. A transaction can occupy more than one space (unit) of the storage. Thus, a transaction can use several units of storage. A library can serve as an example of a storage. It contains a limited number of books. An entering student can borrow any number of books that he wants. The ENTER block keeps the record of the library activity. If the storage is full the transaction can depend upon the number of units that would be occupied by the transaction which seeks entry. If the entering transaction demands more storage units than the unused storage units, entry will be denied to the transaction.

The LEAVE block is the opposite of the ENTER block. The LEAVE block removes a number of units from the contents of the storage. A transaction need not remove the same number of units that is added to the storage. However, as many units should ultimately be removed as were previously added. In the library example, if a student borrows ten books, he may return five books after some time, then three books, and two books at a later time. However, he must return all the ten books that he borrowed initially.

Questions

1. What is the storage that the entering transaction occupies?

2. How many storage units does the transaction utilize?

3. When the transaction leaves the storage how many storage units does it free?

Queue. When a transaction is denied entry to a block it is forced to wait. This causes delay in the progress of the transaction. The QUEUE block is used to measure the delay in the flow of transactions. This block automatically gathers statistical information on the delay of the transaction, such as average delay time, number of transactions in the waiting line (queue), and average number of contents in the queue.

Questions

1. What is the queue where the information should be stored?

2. How many time units are added to the content of the queue by the delayed transaction?

Depart. The DEPART is similar to the LEAVE block. This block is used to remove a transaction from a queue block. Thus, when a transaction encounters this block, computation of the delay time (waiting) is immediately stopped. Each QUEUE must have a corresponding DEPART block. All the contents of a QUEUE block are removed subsequently by one or more DEPART blocks.

Question

1. When a transaction is removed from the queue how many units are reduced from the content of the queue?

Logic. A transaction may make a binary decision. For example, a student passes or fails in a course. Accordingly a record is kept. A logic switch is the record where set (pass) or reset (fail) condition is kept. At later points the condition on the logic switch can be used to make decisions. The LOGIC block is used to determine logic switch condition. The entering transaction in the LOGIC block fixes one of three conditions on a specified logic switch. The three conditions are set, reset, or invert.

Questions

1. What is the change made by the entering transaction?

2. What is the logic switch where the change is made?

Gate. The GATE block is a junction block where a decision is made on the route of a transaction. At this block the path of the transaction is altered. Decisions depend on the system status. The route of the transaction is decided on the basis of the system status and prescribed decision rules. Thus, the GATE block serves a decision point where the status of the system is checked and
transaction is made depending upon the specified alternatives.

The GATE block operates on two modes: a "refusal" or "conditional" entry mode and a "transfer" or "unconditional entry" mode. The conditional mode does not allow entry to a transaction if specified conditions are not met. Thus, the conditional mode would allow a transaction to enter only if the specified condition is satisfied. The transaction is delayed until the specified or desired condition is accomplished.

In the transfer mode, when the desired condition is not satisfied, the route of the transaction is altered. Thus, when the system status is not in a desirable condition, the transaction does not flow in a sequential order, but takes an alternate path.

There are twelve system status conditions, of which one is used for decision-making. There are twelve mnemonics associated with the twelve conditions. They are:

NU = Facility not in use
U - Facility in use
NI = Facility not in preempt state
I = Facility in preempt state
SE = Storage empty
SNE = Storage not empty
SF = Storage full
SNF = Storage not full
LR = Logic switch in RESET state
LS = Logic switch in SET state
M = Check for MATCH condition
NM = Check for no MATCH condition

In order to use the GATE block, the following information is required:

Questions

1. What is the system condition to be tested to make decisions? Select a mnemonic code.

2. If the desired condition is not met, what does happen to the transaction?

Transfer. A transaction flows through a system, going from one block to another. The flow of the transaction is dictated by the system attributes and/or transaction attributes. Normally a transaction moves sequentially, flowing from one block to the next sequentially numbered block; however, this is not always so. The flow may be modified due to system attributes and/or transaction attributes. Changes in the flow of the transaction are made at a decision junction, such as the TRANSFER block.

The change of flow is done at the TRANSFER block. The modification is done in one of four ways: unconditionally, conditionally, statistically, or logically. The choice is specified by a mnemonic selection mode. The mnemonic code blank stands for unconditional transfer which would transfer the transaction to the specified block. The conditional transfer has three options--BOTH, ALL, and SIM. Using the BOTH code one can indicate the next two blocks where the transaction would move to one of the two blocks. If the transaction cannot find entry to the first indicated block, it will try to enter the second block. If the second block also does not allow entry, then the transaction will enter one of the two blocks which becomes available. The ALL code allows the testing of many blocks. The first block and the last path are specified. There is also a provision to test only selected blocks between ranges of the first and last blocks. The SIM condition tests for the condition where all specified blocks are simultaneously free. If free, the transaction moves to the next sequentially numbered block. If the condition is not met, the transaction is delayed until the condition is satisfied.

The statistical transfer refers to the condition where the transaction can take one of two paths depending upon the specified probability value.

Questions

1. What is the mnemonic code?

2. What is the next path that the transaction is to take?

3. If statistical condition is used, what is the probability value associated with each path?

Advance. A transaction moves through the system and operations take place on the transaction. Operations take time to work on the transaction. In other words, the progress of the transaction is delayed. The delay may be due to the process time. For example, a student takes time to learn. The ADVANCE block is used to indicate the time taken in processing the transaction. Thus, this block is used to indicate time to perform an operation in the system. The time is indicated by arbitrary time units, called action time.

Questions

1. What is the average action time?

2. What is the spread of the action time? Is it a constant or a variable? If it is a variable, what is the mathematical function?

Loop. In some cases a transaction should repeatedly undergo the same set of operations. The LOOP block facilitates doing just this. By using the LOOP block a transaction can undergo the same processes many times. Thus, the LOOP block can control the number of times a transaction can pass through a section of blocks. The number of cycles depends upon the content of a parameter of the transaction. For example, if the content of a parameter is five, then the transaction would cycle five times. Thus, the content of the parameter serves as a counter for cycling process. It is also necessary to indicate the starting cycling block.

Questions

1. What is the starting block of the cycle?

2. What is the parameter whose content will be used to indicate the number of looping process?

Split. In cases where one transaction has to undergo more than one operation simultaneously, duplicates can be created from the transaction. For example, in a given time unit, say, a semester a student has to take more than one course at a time. For convenience, it can be considered that each course is taken by a different student. To accomplish this purpose the SPLIT block can be used. The SPLIT block serves the function of creating transactions which are not completely new but are offsprings of a parent transaction. There should exist a transaction which can be used to create siblings.

The transactions (siblings) which are created by the SPLIT block hold identical attributes as those of the parent transaction. However, the offspring need not possess all the attributes that the parent holds. For example, if the parent has ten attributes, its offspring can be created such that they possess only the first six parental attributes. The offspring and their parent can be serialized.

Questions

1. How many duplicates (offspring) need to be created?

2. After the creation where do they go next? What is the next operation (block) on the duplicates soon after their creation?

3. How many of the parental attributes do the offspring inherit?

4. If serialized, what is the parameter where the serial number is kept?

Assemble. An offspring (a duplicate) can belong to only one parent. The parent and its offspring (duplicates) are composed under one assembly set, which can contain any number of transactions (parent and its duplicates). Each transaction that is created by the GENERATE block forms an independent assembly set. When a transaction of an assembly set is terminated the content of the assembly set is reduced by one count. However, the assembly set continues to exist until all members are removed from the set.

Offspring (duplicates) are created by the SPLIT block. The duplicates are created in such conditions when a transaction has to perform more than one operation simultaneously. The ASSEMBLY block performs the opposite operation to that of the SPLIT block. When simultaneous operations are over, the duplicates can be recombined into one transaction. The number of duplicates so combined need not be the same as they were generated by a SPLIT block. For example, the SPLIT block may duplicate ten offspring from one transaction, giving eleven members in the assembly set. The ASSEMBLE block may recombine six of these into one, thus leaving an assembly set consisting of seven members. THE ASSEMBLE block is used to re-combine a specified number of members of an assembly set. Thus, the ASSEMBLE block serves the function of collecting the offspring and recombining them into one transaction.

Question

1. How many offspring are recombined?

Match. The MATCH is used to synchronize the progress of two transactions of an assembly set. This block checks for the condition rather than combining two transactions. The match condition is successful when two siblings enter two MATCH blocks separately, where one MATCH block is the conjugate of the other. When a transaction enters a MATCH block it waits until another transaction of the same assembly set enters the conjugate MATCH block. After the match occurs the two transactions are ready to advance. Thus, the progress of the transactions is withheld until the MATCH occurs.

Question

1. What is the conjugate block?

Gather. When more than two transactions have to be synchronized, the GATHER block can be used. It is similar both to the ASSEMBLE block and the MATCH block. The GATHER block collects more than two transactions like the ASSEMBLE block, but does not destroy any of the transactions. It is similar to the MATCH block since it delays the transactions until necessary conditions are satisfied, then the collected transactions may proceed.

Question

1. What is the number of transactions of the same assembly set that must arrive at the GATHER block before all of the transactions are permitted to proceed?

Mark. A transaction takes time to flow through the system, from one block to another. The time taken by a transaction to flow through from one block to another is called transaction "transit" time. When necessary, the transit time can be computed by using the MARK block. Whenever a transaction enters the MARK block the current clock time (MARK TIME) is recorded in a specified attribute of the transaction. The transit time is equal to the current MARK TIME, minus previous MARK TIME. For example, to measure the transit time of a transaction through a set of processes the MARK TIME is recorded at the beginning of the processes in one of the attributes of the transaction. At the completion of the processes the MARK TIME is recorded on another attribute. The difference between the contents of the two attributes gives the transit time.

Question

1. What is the attribute where the MARK TIME is recorded?

Savevalue. The SAVEVALUE block serves the function of a bookkeeping operation. There are several storage units (record books) where information is stored. The SAVEVALUE is used to store information in a specified place. It stores defined values. When a transaction enters this block the specified information is stored in a cited record for future reference.

Questions

1. What is the SAVEVALUE (record) number where the values should be stored?

2. What is the value to be stored?

Tabulate. This is similar to the SAVEVALUE block. It stores statistical information. The TABULATE block serves as an accounting procedure where necessary statistical analysis is made on the values. The necessary statistical analysis is defined by TABLE definition cards. When a transaction enters a TABULATE block it gathers specified information according to the specified table definition card.

Questions

1. What is the TABLE definition card where the information is to be stored?

2. Are the gathered values weighted? If so, by what factor?

Terminate. Each transaction which enters the system should leave the system ultimately. A transaction leaves the system when certain conditions are met. For example, a student leaves the school system when he successfully completes the requirements. A transaction comes out of the system via the TERMINATE block. The block removes transactions from the system.

In a simulation process, a "run termination count" is used to indicate the total number of transactions that should run through the system before printing the final summary statistics of the system variables. When a transaction enters the TERMINATE block, the transaction removes a specified number of termination counts. The total terminal count is reduced by the amount that the transaction carries along with it when the transaction enters the TERMINATE block. When the terminal count reaches zero or less the system shuts down. If this does not happen, the simulation model runs indefinitely. Theoretically it is feasible that some transactions may be stranded within the system when the system shuts down. Unless it is deliberate, caution should be taken that such a condition (stranding transactions in the system) be avoided.

Question

1. How many terminal counts of transactions are removed from the system when a transaction enters the TERMINATE block?

Test. The TEST block serves the function of comparing two arguments, and the resulting condition will dictate the flow of the transaction. The condition is specified in the form of an algebraic comparison between the two arguments. If the desired condition exists the transaction will proceed in the usual manner. If the stated condition does not occur, one of two actions will be taken on the transaction. The transaction will wait until the desired condition is attained or the transaction will be directed next to a specified block. For example, a student's grade can be tested to see if it meets the passing level. If the grade meets the condition, the transaction moves in the usual manner. If it is not so, the student may be asked to repeat the course, or wait until the passing level is changed.

There are six mnemonic codes to specify the desired condition.

L The desired condition is the first argument less than the second argument.

LE The desired condition is that the first argument is less than or equal to the second argument.

E If the first argument equals the second, the desired condition is satisfied.

NE If the first argument is not equal to the second argument, the condition is satisfied.

G The desired condition is that the first is greater than the second.

GE The first argument is greater than or equal to the second argument

Questions

1. What is the desired mnemonic code?

2. What is the first argument?

3. What is the second argument?

4. If the desired condition is not satisfied what happens next to the transaction? What is the next block?

Prior to gathering information for the GPSS blocks, general information about the system is deamed necessary to construct flow-charts of the system. The general information would dictate selection of appropriate blocks whose sequence specified the flow diagram. A procedure is given in this section which would be helpful in gathering information about the system so as to use the GPSS blocks in flow-charting the system.

The collection of information can be encompassed under four categories. Information on the first category deals with the input of the system. The second category pertains to resources available in the system. Information about the system activities forms the third category. The last is concerned with the output information.

Transaction. Inputs to the system are defined as transactions in the GPSS terminology. As the inputs initiate the system activities, they form a good starting point to gather information about the system. Initiation of system activities starts with generating transactions. The following questions facilitate collecting information concerning the transaction.

Questions

1. What are the transactions to the system?

2. Identify the populations from which the transactions are drawn.

3. How many different populations are there? Each population requires a GENERATE block.

4. Is there an upper limit on the number of transactions drawn?

5. If so, how many transactions are drawn from each population? (See GENERATE block).

6. What are the characteristics of each population?

7. Do the characteristics dictate different priority levels on the transactions? If so, what is the priority level? (See GENERATE block.)

8. How many attributes (parameters) are necessary to describe a transaction? (See GENERATE block.)

9. What are the initial attribute values? (See ASSIGN block.)

Resources. Resources refer to the facilities, storages, and the logic switches associated with the system. Resources offer services that the transactions have to use to undergo changes in their attributes. A facility will offer services to only one transaction at a time. Many transactions can use the services of a storage. However, a storage has a finite capacity. A logic switch records the result of binary decision, which is useful in directing the transactions.

Questions

1. How many facilities are available in the system?

2. How many storages are available in the system?

3. What is the capacity of each storage?

4. How many logical switches are there?

Components. System components refer to the activities that a transaction goes through. These activities not only direct transaction flow but also modify the transaction attributes. Thus the system activities can be classified under two groups. The activities under the handling group dictate the flow of a transaction. The second group of activities modify or change the transaction attributes.

Questions (Handling Group)

1. How many activities does a transaction undergo simultaneously? (See SPLIT block.) This indicates the number of parallel activity paths of a transaction.

2. When does a transaction have to perform simultaneously?

3. When does the simultaneous operation stop? This indicates convergence of parallel paths. (See ASSEMBLE block.)

4. What are the processes that delay access to transactions and by so doing form waiting lines? (See SEIZE and ENTER blocks.)

5. Where are the waiting lines located? (See QUEUE block.)

6. Do all transactions have the same priority for processing? (See PRIORITY and PREEMPT blocks.)

7. If extant, are there two or more simultaneous activities that must be satisfied before a transaction can proceed? (See MATCH and GATHER blocks.)

8. Are the system attributes used to modify or delay the transaction flow? (See GATE block.)

9. When is the transaction attribute used to modify the flow? (See TRANSFER block.)

10. When and what are the two arguments that are used to change the transaction flow? (See TEST block.)

11. What are the activities that require a set of repeated operations? (See LOOP block.)

12. When does a transaction leave the waiting line? (See RELEASE, LEAVE, and DEPART blocks.)

13. How much processing time is required at each facility or storage? (See ADVANCE block.)

After obtaining information about the above questions, and using the information as guidelines, answer the following questions.

14. What are the major activities of the system?

15. What are the sequential activity paths taken by the transactions?

<u>Questions</u> (Modifier Group)

1. How many times are transactions attributes altered?

2. When do they change?

3. How are they modified? Can any mathematical functions be developed? If so, what are the functions? (See ASSIGN block.)

4. When is only the first attribute of the transaction altered? (See INDEX block.)

5. When are the priority values assigned to the transactions? (See PRIORITY block.)

6. Is the transit time to be kept? If so, from what initial point to what terminal point in the system? (See MARK block.)

Output. The output information is concerned with bookkeeping pertaining to system and transaction activities. The information comes out in printed forms, when all transactions leave the system. It is necessary, however, to specify the record-keeping format.

Questions

1. When does a transaction leave the system? (See TERMINATE block.)

2. What type of information is collected? (See Table 9.)

3. What is stored in the system memory for future action? (See SAVEVALUE and TABULATE blocks.)

4. How many records (books and tables) are required to keep the information? (See TABULATE and SAVEVALUE blocks.)

5. Is it necessary to calculate the frequency distribution? If so, how many frequency classes and what are the upper limits? (See TABULATE block.)

Table 9. Standard numerical attributes

| Entity | Symbol | Meaning |
|---|---|---|
| Transactions | P | Parameter, fullword<br>halfword |
| | PR | Priority |
| | MI | Transit Time |
| | MP | Parameter Transit Time |
| Blocks | N | Total Entry Count |
| | W | Current Count |
| Facilities | F | Status of Facility |
| | FR | Utilization (Parts/Thousand) |
| | FC | Entry Count |
| | FT | Average Time/Transaction* |
| Storages | S | Current Contents of Storage |
| | R | Remaining Contents |
| | SR | Utilization (Parts/Thousand) |
| | SA | Average Contents* |
| | SM | Maximum Contents |
| | SC | Entry Count |
| | ST | Average Time/Transaction* |
| Queues | Q | Current Length of Queue |
| | QA | Average Contents* |
| | QM | Maximum Contents |
| | QC | Total Entry Count |
| | QZ | Number of Zero Entries |
| | QT | Average Time/Transaction* |
| | QX | Average Time/Transaction Excluding Zero* |
| Tables | TB | Table Mean* |
| | TC | Entry Count |
| | TD | Standard Deviation* |
| Savevalues | X | Fullword Savevalue |
| | XH | Halfword Savevalue |
| Groups | G | Number of Items in Group |
| Functions | FN | Function |

*Truncated to an integer

Appendix B

Algorithm for Solving the Project Selection Problem

The project selection problem can be stated as follows:

$$Y = \sum_{j=1}^{N} h_j e^{-c_j s_j}$$

subject to

$$\Sigma s_j = M, \text{ and } s_j \geq 0,$$

where $$h_j = 2r_j k_j .$$

The problem satisfies the conditions established by Kuhn and Tucker, which require that the normal to the functional in the problem be expressed as a non-negative linear combination of the normals to the constraints that are critical, that is, the constraints that are satisfied as equalities. These conditions become

$$\frac{\delta y}{\delta s} = (-c_1 e^{-c_1 s_1 h_1}; -c_2 e^{-c_2 s_2 h_2}; \ldots\ldots; -c_j e^{-c_j s_j} j_j; \ldots; -c_n e^{-c_n s_n h_n})$$

$$+ - h (1, 1, \ldots, 1_j, \ldots, 1) + \sum_{j-1}^{N} v_j (0,0,\ldots,1_j, \ldots 0)$$

where $v_j \geq 0$ and $v_j = o$ if $S_j >$ so that

$$c_j e^{-c_j s_j} j_j = h \qquad j \in J \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$c_j h_j = h - v_j \qquad j \notin J \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where J is the set of all indices for which $S_j$ is positive where $j \notin J$ means that the associated $S_j$ are not members of this set. That is, for $j \notin J$, $s_j = 0$ in all cases.

If we let

$$\hat{f}_j - \ln (c_j h_j)$$

the (1) and (2) can be written as:

$$\hat{f}_j - c_j s_j = \ln \mu \qquad j \in J \ldots\ldots\ldots (3)$$

$$\hat{f}_j \leq \ln \mu \qquad j \notin J \ldots\ldots\ldots (4)$$

Rewriting equation (3) as

$$\frac{\hat{f}_j}{c_j} - s_j = \frac{\ln \mu}{c_j} \qquad \ldots\ldots\ldots\ldots (5)$$

and recalling the constraint that

$$\sum_{j-1}^{N} s_j = \sum_{j\varepsilon J} s_j = M$$

equation (5) can be summed to obtain

$$\sum_{j\varepsilon J} \frac{\hat{f}_j}{c_j} - M = \ln\mu \sum_{j\varepsilon J} \frac{1}{c_j}$$

or

$$\ln\mu = \frac{1}{\sum_{j\varepsilon J} 1/c_j} \left( \sum_{j\varepsilon J} \frac{\hat{f}_j}{c_j} - M\right).$$

Knowing that $c_j s_j > 0$, $j\varepsilon J$, equation (4) can be rewritten as

$$\hat{f}_q \leq \frac{1}{\sum_{j\varepsilon J} 1/c_j} \left( \sum_{j\varepsilon J} \frac{\hat{f}}{c_j} - M\right) < \hat{f}_r$$

for all $r\varepsilon J$ and $q\notin J$.

The necessary and sufficient condition for the selection of indices $r\varepsilon J$ becomes

$$\min_{r\varepsilon J} \hat{f}_r > \frac{1}{\sum_{j\varepsilon J} 1/c_j} \left( \sum_{j\varepsilon J} \frac{\hat{f}_j}{c_j} - M\right) \geq \max_{q\varepsilon J} \hat{f}_q$$

and the optimal $s_r^*$, $r\varepsilon J$,

$$s_r^* = \frac{1}{c_r} \left[ \hat{f}_r - \frac{1}{\sum_{j\varepsilon J} 1/c_j} \left( \sum_{j\varepsilon J} \frac{\hat{f}_j}{c_j} - M\right)\right]$$

Algorithm for computer programming:

I Compute

$\hat{f}_j = \ln (2r_j c_j k_j)$ for all j where $j = 1,2, \ldots N$.

II Sort $\hat{f}_j$s in decreasing order and renumber such that

$\hat{f}_1 \; \hat{f}_2 \; \ldots \ldots \ldots \ldots \; \hat{f}_N$,

and tail respective $r_j$, $k_j$, and $c_j$s.

III Compute

$$c_1 \left(\frac{\hat{f}_1}{c_1} - M\right)$$

If $c_1 \left(\frac{\hat{f}_1}{c_1} - M\right) \geq \hat{f}_2$, allocate all resources to first project and stop.

If $\hat{f}_2 \quad c_1 \left[\frac{\hat{f}_1}{c_1} - M\right]$, continue and

IV Compute

$$\frac{1}{\sum_{i=1}^{2} \frac{1}{ci}} \left[\sum_{i=1}^{2} \frac{\hat{f}_i}{c_i} - M\right].$$ If it is greater than $\hat{f}_3$, stop.

Otherwise

V Continue until some project $f_{k+1}$ is found such that

$$\frac{i}{\sum_{i=1}^{k} \frac{1}{c_i}} \left[\sum_{i=1}^{k} \frac{\hat{f}_i}{c_i} - M\right] \geq f_{k+1}.$$

Then allocate resources to projects 1,2,3, ... k and stop. The k can range from 1 to N.

VI For each project i selected, i=1,2, ... K, compute

$$s_i = \frac{1}{c_i} \quad \hat{f}_i - \frac{1}{\sum_{k=1}^{k} \frac{1}{c_j}} \quad \left(\sum_{j=1}^{k} \frac{\hat{f}_j}{c_j} - M\right) \quad ,$$

where $s_i$ is the resources allocated to the $i^{th}$ project, and k is the number of projects to which resources are allocated.

Appendix C

Computer Program for Project Selection

The computer program of the project selection process is listed below. The program is written in FORTRAN IV language. The program performs the project selection process on sets of projects, one set at a time. A set can contain up to one hundred projects. The number of projects in the set and the total available resources for the set of projects are specified in a set description card.

## Set Description Card Format

Col. 1-4 Number of projects in the set (right justified integer).

Col. 5-12 Total resources, M (with a decimal point).

The set description card is followed by the project description cards. A project description card contains (1) project code, (2) sensitivity level (c), (3) utility (return) value (r), and (4) limiting probability value (k). There would be as many project description cards as specified in Col. 1-4 of its set description cards.

## Project Description Card Format

Col. 1-4 Project code (four alphanumeric characters).

Col. 5-12 Sensitivity value (c), with a decimal point.

Col. 13-20 Return (utility) value (r), with a decimal point.

Col. 21-28 Limiting probability value (k), with a decimal point.

After performing project selection process on a set of projects, the program reads the next set description card. Depending upon the number specified in Col. 1-4 of the set description card, the program either continues reading the project description cards, or the program terminates the selection process. In order to terminate the program, the very last card should contain a zero in Col. 1-4.

```
C     PROGRAM FOR PROJECT SELECTION MODEL
C     FIRST CARD CONTAINS NUMBER OF PROJECTS AND TOTAL AMOUNT OF MONEY
C        IN (13,F8.0) FORMAT
C     EACH PROJECT CODE, SENSITIVITY, RETURN, AND LIMIT.PROBABILITY IN
C        (A4,3F8.0) FORMAT
C     AFTER PROCESSING ONE SET OF PROJECTS THE PROGRAM READS THE FIRST CARD
C     IF NPROJ = 0, THE PROGRAM TERMINATES
      DIMENSION A (100), R(100), PK(100), CODE (100), F(100)
  102 READ (1,1) NPROJ, SMON
  1   FORMAT (13,F8.0)
      IF (NPROJ - 0) 101,101,100
  100 E2 = 0.
      WRITE (3,110) NPROJ, SMON
  110 FORMAT ('1 NUMBER OF PROJECTS = '13,' TOTAL RESOURCES = 'E16.8)
      WRITE (3,15)
   15 FORMAT ('0  CODE          SLOPE          LIMIT PROBABILITY
     1RETURN')
      DO 3 J=1, NPROJ
      READ (1,2)  CODE (J),A(J)*R(J)*PK(J)
      E2 = E2+R(J)
      F(J) = ALOG (2.*A(J)*R(J)*PK(J))
    3 WRITE (3.16)  CODE  (J),A(J),PK(J),R(J)
   16 FORMAT (4X,A4,3X,E16.8,4X,E16.8)
      JM = NPROJ - 1
    2 FORMAT (A4,3F8.0)
    7 JK = 0
      DO 4 J = 1,JM
      IF (F(J+1) - F(J)) 4,4,5
    5 JK = JK+1
      J2 = J+1
      B = F(J)
      F(J) = F(J2)
      F(J2) = B
      B = A(J)
      A(J) = A(J2)
      A(J2) = B
      B = CODE (J)
      CODE (J) = CODE (J2)
      CODE (J2) = B
      B = PK(J)
      PK (J) = PK(J2)
      PK(J2) = B
      B=PK(J)
      R(J) = R(J2)
      R(J2) = B
    4 CONTINUE
      IF (JK) 6,6,7
    6 NPS=0
      NPS = 0
      DO 9 J = 1, JM
```

```
      D1 = 0.
      D2 = 0.
      DO 8 J1 = 1,J
      D1 = D1 + (1./A(J1)
  8   D2 = F(J1)/A(J1)+D2
      C = (1.0/D1)*(D2-SMON)
      NPS = NPS+1
   IF (C-F(J+1))9,9,10
 10   GO TO 11
  9   CONTINUE
      NPS = JM+1
      D1 - D1 +1./A(NPS)
      D2 = D2+F(NPS)/A(NPS)
 11   DOL=0.
      WRITE (3,18) NPROJ,NPS
 18   FORMAT ('1      OUT OF '13,' PROJECTS THE PROJECT SELECTION MODEL ALLOC
     1ATES RESOURCES TO '13,' PROJECTS'/'0  FOLLOWING TABLE SERVES GUID
     2ELINES IN DECISION-MAKING')
      WRITE (3,20)
 20   FORMAT (') PROJ.CODE      RETURN          SUSC.PROB.          ALLOCATED RE
     1SOURCE        CUM.REWARD       CUM.RESOURCE')
      E1 = 0
      D3 = (1.0/D1)*(D2-SMON)
      DO 12 J = 1,NPS
      D = (1./A(J))*(F(J)-D3)
      DOL = DOL+D
      P = PK(J)*(1.-EXP(-A(J)*D))
      E1 = E1+(2*R(J)*P)
      ER=E1=E2
 12   WRITE (3,13) CODE (J),R(J),P,D,ER,DOL
13    FORMAT ('0      'A4,5(2X,E16.8))
      GO TO 102
101              CALL EXIT
      END
```