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AN EXAMINATION OF TERMINAL-BASED MATHEMATICAL MODELS

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by

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BACKGROUND OF THIS PAPER

This paper is based on studies being conducted at the Bureau of Business Research as part of a research program on organizational planning. It was prepared for presentation at the 1971 American Accounting Association held at Lexington, Kentucky, August 1971.

ABSTRACT

This study grew out of the recent trend toward closely-coupled, man-machine decision systems which have been made possible by the advent of online computer systems. The study is aimed at evaluating the effect of terminal systems on the use of mathematical models and the resulting dynamics within an organization's information environment. It represents a proposed addition to our present understanding of the needs and characteristics of terminal decision units, an understanding which will be the basis for advanced management information system design and development.

In the past decade work in the area of terminal systems has been largely oriented toward the technical problems of developing the necessary computer system components. Relatively little research has been carried on to relate the transformations in the decision system brought on by online applications to other organizational systems. The analysis in this paper is an effort to overcome certain of these shortcomings.

I

INTRODUCTION

Rapid developments are being made in the realization of computer systems which are both easily accessible and convenient aids to human intellectual processes. We are, in fact, approaching an era in which the concept of a closely-coupled, man-machine-information network will become a reality within the management information systems of organizations. The orientation of this research project is toward certain specific problem areas related to transversing the boundary of this era--designing an information system that can effectively meet the information needs of decision units in which online computer systems play an integral role in the problem-solving processes.

This study represents a preliminary effort at a systematic analysis and conceptualization of the needs and characteristics of terminal decision units. The components making up a terminal decision unit include a human element that has a direct interaction with data bases and formal models through the medium of an online computer system. Gaining an understanding of the terminal decision organism is a key to the successful development of the next generation of management information systems.

A basic rationale for this work is the belief that online applications will have a significant effect on the information needs of decision makers. The failure to meet the information needs of evolving terminal decision units <u>has</u> resulted and will continue to result in frustrations leading to barriers against online system usage and the related organizational benefits which have been well documented in the literature and practice.1/

This paper examines one facet of the possible dynamics arising from the use of terminal-based systems within an organization's environment. The dimension considered is the transformation in the role of computer-based mathematical models as a computational partner in a heuristic problem-solving team.2/ The findings of the study suggest that terminal-based systems can offer a computational architecture which will affect both the extent to which formal models are used within organizations and the types of models employed.

The background for the study has been an examination of the use of various online systems within both manufacturing firms and commercial banks. The study also builds on existing literature in the area of online systems. The literature has tended to be structured around discussions of computer hardware and software and some generalizations about the nature of human problem solving in a terminal environment. The orientation of this paper is somewhat unique in that it emphasizes the man-model interface and its implications for information systems design.

Mathematical models

The term "mathematical models" can be broadly defined as symbolic representations stated in terms of mathematical notation. Within the framework of this paper it is appropriate to include in this definition logic or descriptive models, such as those specified according to current accounting or other parafinancial considerations.

To establish a proper perspective of mathematical models within the construct of a terminal decision unit it is helpful to view them as part of a system which is defined by a vector consisting of the following components: abstraction, manipulation, interpretation, and experimentation.[3/]

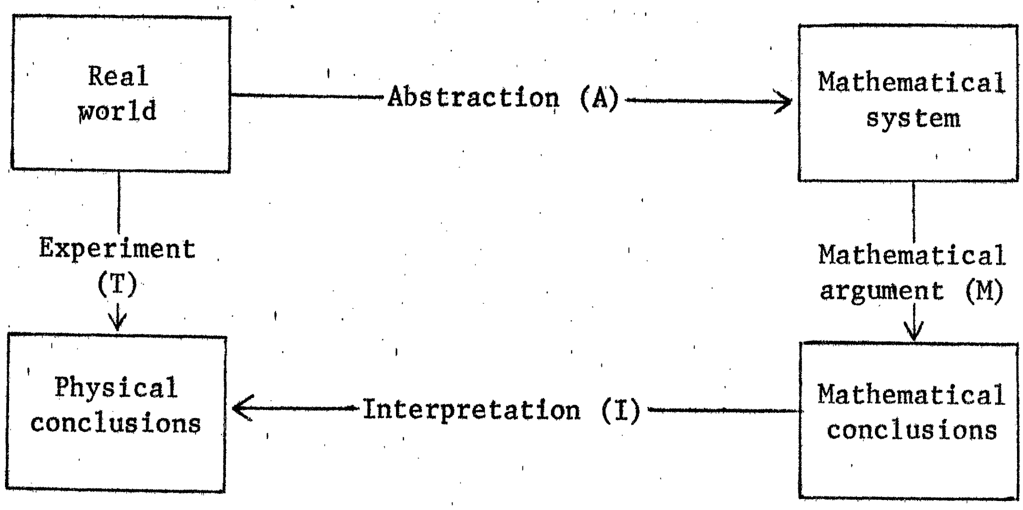

Fig. 1.

The man-model relationship can be described in the following manner. An analyst begins with some aspect of the real world and by means of a process called abstraction (A) maps his objective system into some mathematical system, called the mathematical model. Following the abstraction, the analyst uses mathematical arguments (M) to arrive at theorems or mathematical conclusions. The conclusions are then interpreted (I) into physical conclusions about the real world. The physical conclusions arrived at through the AMI (abstraction, mathematical model, interpretation) process can be checked by experiment or test (T), and the validity of the model is measured by the closeness of fit between the test results and the theoretical results.

The benefits to be derived by a decision maker from the use of mathematical models are legion. A decision maker must deduce from data received the past, present and future behavior of relevant environmental systems for purposes of choosing among alternative courses of action in order to bring about desired behavior. But he is constrained in making the necessary decisions because of his incapacity to store and manipulate large quantities of data and his inability to deal with extensive amounts of unstructured data.

A computer-based mathematical model enables a decision maker to use an abstraction of real world phenomenon and the calculating and data storage capabilities of a computer as a basis for combining scattered pieces of data into an integrated and meaningful picture of the component states of relevant environmental systems. By facilitating feature extraction such a model can help overcome certain of the cognitive limitations associated with estimating system states and interrelationships.

The capabilities of the computer, harnessed through the use of formal models, can also allow the decision maker to experiment more readily with various environmental situations. Computerized mathematical models can assist the user in the ranking of alternatives under various sets of assumptions through parametric investigations and sensitivity analysis. In this sense, such models can sharpen management's judgment and extend the range of its intuition by permitting a decision maker to correct readily his prior probability space and component values of state vectors.

Management scientists have not found it too difficult to construct mathematical representations of processes related to various aspects of decision making. However, the effect of such systems on managerial processes has been limited. For the most part, decision makers have found computational systems structured around large-scale automata unusable in their present state except for the purposes of data retrieval and solving highly structured arithmetic calculations. The price of the introduction of available computational systems has often been a combination of oversimplification and overcomplication--oversimplification of the actual process and overcomplication in the application of analysis. The toll of these excesses has tended to force management to learn to get along without a dynamic interface with mathematical models by establishing their own internal systems to accumulate a semblance of the information which they might acquire.

The evolution of terminal-based systems has reduced and will continue to reduce the barriers in the use of computer-based models. The effect within organizations that participated in the study appears to be a stimulation toward greater use of formal models in decision-making activities. The related environmental dynamics are also represented by variations in the extent to which certain types of algorithms are used within an organization.

A catalyst for these transformations which acts as a focal point for this paper is the evolving role of the human in the computational operant. This is a result of the employment of terminal systems within organizations. In a very real sense a user's perceptions of the world become a primary input into mathematical analysis; or, in other words, the experience and insight of managers are integrated into the analytical framework. The resulting heuristic-analytic loop can, given the findings of this study, overcome a number of the barriers which have restricted the role of computer models as partners in decision-making activities.

In many ways this paper is analogous to the Bayesian philosophy. It is concerned with a broader base of analytical techniques and the relevant interface between the subjective and objective elements is not Bayes's theorem but an online computer system. Within this framework it is proposed that the essence of terminal-based mathematical models may be distinguished by the role of the user's heuristic capabilities in the computational architecture.

This paper begins with a brief explanation of certain technical advancements which have affected the character of terminal decision. Sections III and IV deal with the nature of user involvement in terms of model and data-base design and development. Section V expands on the heuristic role in the computational architecture, and Section VI on the impact of the research findings on data needs of decision units.

II

TERMINAL-BASED MAN-MODEL COMMUNICATION CHANNELS

Activities related to the use of computer-based mathematical models include: (1) translation of intuition to a mathematical form, (2) transformation of the mathematical form to machine-readable form, (3) a computational phase, and (4) interpretation and testing of the results of the analysis.

Traditionally, the decision maker has continually had to rely on operation researchers, systems analysts, programmers, and machine operators on a continuing basis to assist him in the use of mathematical models. Such computational systems tended to be characterized by a high level of noise, frustration, inaccessibility, as well as unacceptable time delays arising in the coding, calculation and translation of a given datum. In general, the system controlled the schedule of the problem-solving activities of the user. With some degree of certainty, one can suggest that the attributes of such computational systems have severely restricted the extent to which mathematical formulations are used within organizations.

The man-model communication channel has been significantly reshaped by the evolution of online computer systems. In particular, the user now has the capability of direct access to models and data bases stored within the computer information structure. As is pointed out in this paper, this type of man-model linkage can play an important role in overcoming technical, economic and psychological constraints related to the use of mathematical models in all aspects of problem-solving activities. Figure 2 illustrates certain aspects of the computational architecture restructuring which can be traced to the evolution of terminal systems. The resulting system design suggests greater participation by the user in many of the phases of model usage.

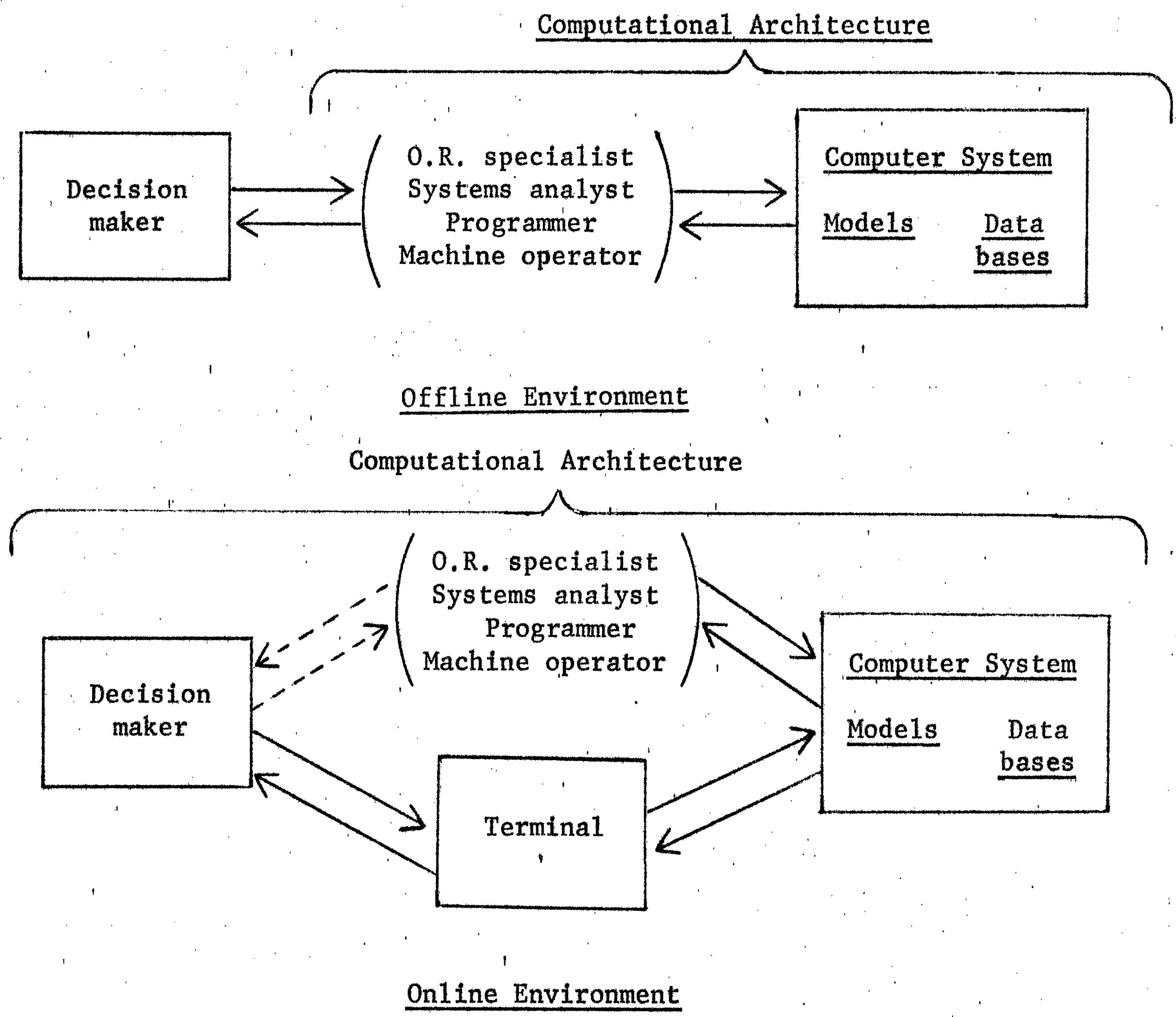

Fig. 2.

Conversational computing

The feasibility of integrating mathematical models into heuristic problem solving has been enhanced by the concept of conversation computing. In this mode the decision maker can interact with the system by using commands similar to, if not identical with, his native language. Progress in the areas of compiler and terminal design have largely overcome the complex problems related to the intelligible communication between the system and the user. For example, on request the system can both review the model structure and needed data input for the human and then request input data in highly structured and easily understood format.

The effect of having the user directly interact with a computer information structure is, in part, a reduction in the time and effort expended on the necessary abstraction and interpretation phases of model development and use. Interacting directly with the computational and data storage capability of a computer system can improve the efficiency with which a decision maker carries his intuition through the relevant translations described by the AMI process--intuition to mathematics to computer-accessible form to computation and interpretation. The effect of direct-access computer systems on the economics of model usage is also represented by the concept of computer and model utilities.

Computer and model utilities

Advances in computer technology and data-management techniques have resulted in multiple-access systems which have been characterized as utilities. Such systems can support a large number of users whose usage time and job characteristics may be seen as being random in character. Time-sharing computer systems can reduce the cost of employing the computer resource in different phases of model use and development.

In a similar sense the large model banks which are supported by many commercial vendors may also be thought of as utilities and can have a similar effect on model usage cost. This is becoming especially true as the systems present the user with a flexible set of model building blocks. Many models are now available in this mode that have built-in flexibility, thereby permitting the user to consider a number of different alternatives in terms of variable definitions and relationships. Also, the user is often able to tie together various algorithmic techniques in order to create a model which best meets his own needs. The development and maintenance costs of models in this type of system can be shared by a large number of users. The effect is a significant cost savings for each of the individual users of a model utility.

The evolution of terminal systems has enabled a closely-coupled, heuristic-analytic loop to become both technically and economically feasible. A resultant transformation which is occurring in decision systems is that bottle necks related to the use of computer-based mathematical models have shifted from the analytic to the heuristic elements of the system.

Real-time systems

To an ever greater extent, firms are meeting the challenge of an increasingly dynamic environment by employing telecommunication and other terminal systems for the purposes of "real-time decision making." It is important to point out that a system which is capable of real-time information transmission is necessary but not sufficient for real-time decision making. The information system must facilitate decision making in real time by supplying the decision maker with the tools necessary to exist in a rapidly changing business environment.

Coping with evolving environmental dynamics will require most managers to adopt a new stance toward the future. The past will become less and less a viable basis for decision making. In such instances, perhaps the only way to obtain needed qualitative data for decision making is by means of suitably chosen quantitative data. But, implicit in such a decision-making framework is a human who is operating online with a set of mathematical models and data bases frequently modifying and restructuring both his hypotheses and action space through experimentation. To exist in a real-time environment, decision-makers may well be forced to integrate models and online data-retrieval techniques into their problem-solving activities.

Summary

A key underpinning to this study is the idea that terminal systems can play a dominant role in overcoming various barriers related to the use of computer-based mathematical models. The effect will be felt in terms of a model dynamics defined by the extent to which formal models are used and the types of models commonly employed within organizations.

The next sections of the paper expand on various facets of this argument. It is important to note, however, that internal and external pressure arising from the increasing rate of environmental change (in part reflected in the evolution of high-speed data transmission systems) is likely to force users to telescope the time frame of their historical perspective and into the use of "laboratory" experimentation structured around a network of computer-based mathematical models.

III

MODEL DEVELOPMENT

In the past, users--and even more important, potential users --of computer-based mathematical models in a management environment had little or nothing to do with the design and development stages of the algorithmic systems. Model builders and users tend to exist in two different worlds which are likely to vary in terms of methods, goals, and philosophical climates. For example, model builders often deal in generalities, while the user must deal with specifics; the builder is likely to be motivated by efficiency of computation, the user with the effective realism of a system.

In contrast, an attribute of the terminal decision systems within participating organizations is a growing user participation in model development and implementation. Examples are some major New York banks in which a large percentage of their operating terminal mode models have been conceived and developed by users. The prerequisite training for many of those interviewed was instruction in a computer language such as basic and at least some exposure to certain statistical and analytical techniques. This rather limited technical background was supplemented by a terminal system's capacity to affect user learning and the system networking capabilities within a terminal environment.

Effect on learning

The extent to which a model will be used is largely a function of the level of understanding of the model by the user. The initial conceptualization by the average manager of existing computer-based computational systems is characterized by confusion, doubts, and missing information--in short, it may be characterized by a high degree of uncertainty.

This uncertainty can be overcome through experimentation and learning. However, given the training of most decision makers, the time and effort needed to gain the necessary appreciation of a model structure and data requirements has prevented the required learning process from taking place.

Man-machine interaction through a terminal system can help in overcoming this problem by effecting the learning process in terms of experimentation, reinforcement and instruction. Given the findings of this study, one can hypothesize that the effect on the learning process is sufficient enough to allow individuals with limited technical training to make use of and participate in the development of mathematical models.

In the case of models which already exist, a terminal system can introduce the user to the issues and problems related to model usage much faster than otherwise possible. A person can rapidly get a feel for how the model works through direct experience. For example, insight into the validity of a model can be obtained by varying the input parameters and/or the decision variables and checking to determine whether the output of a model behaves in a plausible manner.

Didactic teaching which can be programmed into a man-machine interaction can also effect the learning process related to model usage. Existing systems have the capabilities to:

1. Provide answers to questions. For example, the system can, on request, both review the model structure and needed input for the decision maker.

2. Evaluate recommendations. Systems can evaluate responses of users as to whether they are correct or incorrect. A simple example is common diagnostics.

3. Assist decision makers who are having trouble either answering questions or recommending appropriate responses. At any point in the dialogue the user has the flexibility to request specific help from the system and receive appropriate instructions.

This type of instruction can reduce the understanding needed to employ certain techniques in the decision-making process.

Practice and instruction alone do not produce learning. In order to ensure learning, it is necessary to employ the operation of reinforcement. A reinforcer is any object or event that, when presented with a response, serves to increase or maintain the strength of a response. The timing of reinforcement in learning is important. The immediate response possible in a terminal environment can more readily allow the learner to zero in on a correct response, thus significantly increasing the efficiency of the learning process.

The following dialogue is representative of the type of instructional support available on many inhouse and commercially offered time-sharing systems.[4/] In this particular case the system is questioning the user as to the type of output desired. At any point the human may request assistance by responding with the command "help."

(System) FOR BALANCE SHEET: CHOOSE PERCENTAGE (%) OR DOLLAR ($) REPORT?

(User) HELP

(System) YOU MAY HAVE THE PRO FORMA YOU HAVE REQUESTED EXPRESSED IN PERCENTAGE TERMS (TYPE %) OR IN DOLLARS (TYPE $).

(System) CHOOSE PERCENTAGE (%) OR DOLLAR ($) REPORT?

(User) $

(System) ALL REPORTING PERIODS (YES OR NO)?

(User) HELP

(System) TYPE YES IF YOU WANT BALANCE SHEET AND INCOME STATEMENT DATA FOR EVERY PROJECTED PERIOD. THE SHORT FORMS, BOTH BALANCE SHEET AND INCOME STATEMENT, PRINT SIX PERIODS ACROSS THE PAGE. THE LONG FORMS ONLY PRINT FIVE PERIODS.

(System) ALL REPORTING PERIODS (YES OR NO)?

(User) NO

(System) FOR EACH COLUMN, SELECT REPORTING PERIOD?

(User) HELP

(System) THE BALANCE SHEET REPORT WILL PRINT UP TO SIX PERIODS ACROSS THE PAGE FOR THE SHORT FORM (FIVE FOR THE LONG FORM). YOU MAY SELECT THOSE PERIODS YOU WANT IN ANY ORDER (INCLUDING PERIOD 0 IF YOU WANT BEGINNING BALANCES). SEPARATE EACH PERIOD REQUEST WITH A COMMA.

A rationale for predicting greater user involvement in the development of models can also be tied to the trial-and-error accumulative learning process which is possible in a terminal environment. In creating a model, rarely can one expect the initial set of variable interconnections to generate the desired input-output behavior. Several trial interconnections are usually analyzed with the developer learning through experimentation. Such a learning process can be made more efficient in a terminal system, and reduce thereby the time and effort expended on model development and bringing this process into the feasible set of activities carried on by decision makers. In other words, given some information concerning the structure of a system and some observations of inputs, outputs, and internal behavior over time, the model developer can quickly determine the missing information concerning structure, inputs, and outputs.

Networking capabilities

Direct access to a model bank also enables a user to network together various model building blocks. The employment of modular design techniques has allowed easier model synthesis. For example, making a model more complex is a relatively simple matter for the user. He can break old connections and introduce new parameters in a matter of minutes. This approach is to be contrasted with the more conventional approach involving difficulties with intuitive interaction and expenditure of time.

One of the systems studied included a hierarchy of models which could be readily networked together in a terminal mode in order to match the computational architecture with a user's needs and abilities. The basic level of the system was characterized by a deterministic simulation model defined by a parafinancial logic structure. This stage offers the user a laboratory to experiment with different environment-decision-performance relationships. The output is defined by financial reports required for internal reporting purposes.

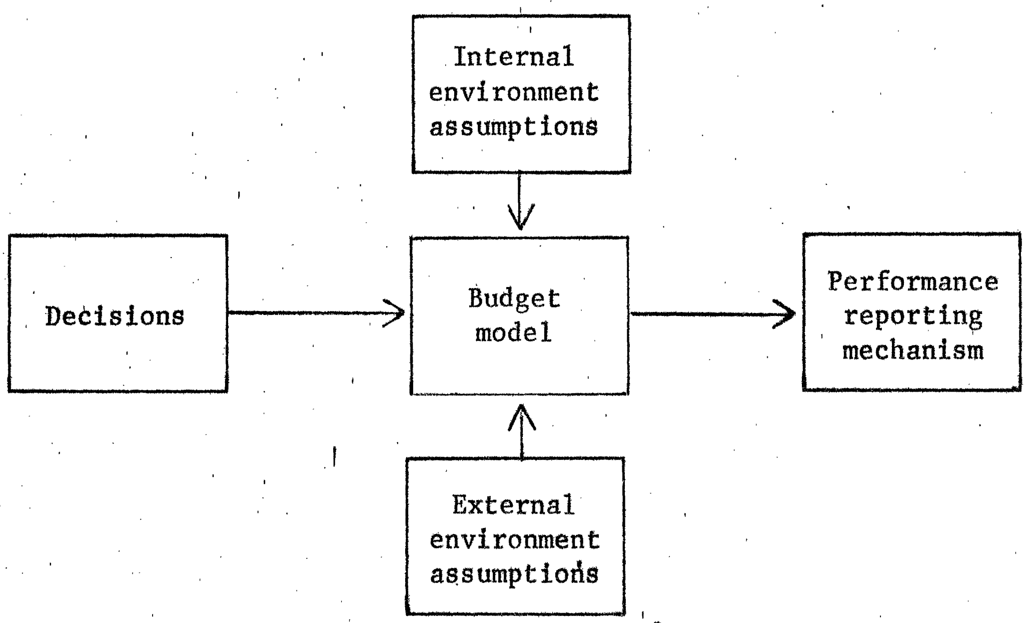

Fig. 3.

Given this basic structure, the user can draw upon a system of statistical techniques to assist in the representation of the element of uncertainty. The networking of the two systems makes possible probabilistic statements about the future. The new system accepts both present decisions and future policies related to decision rules.

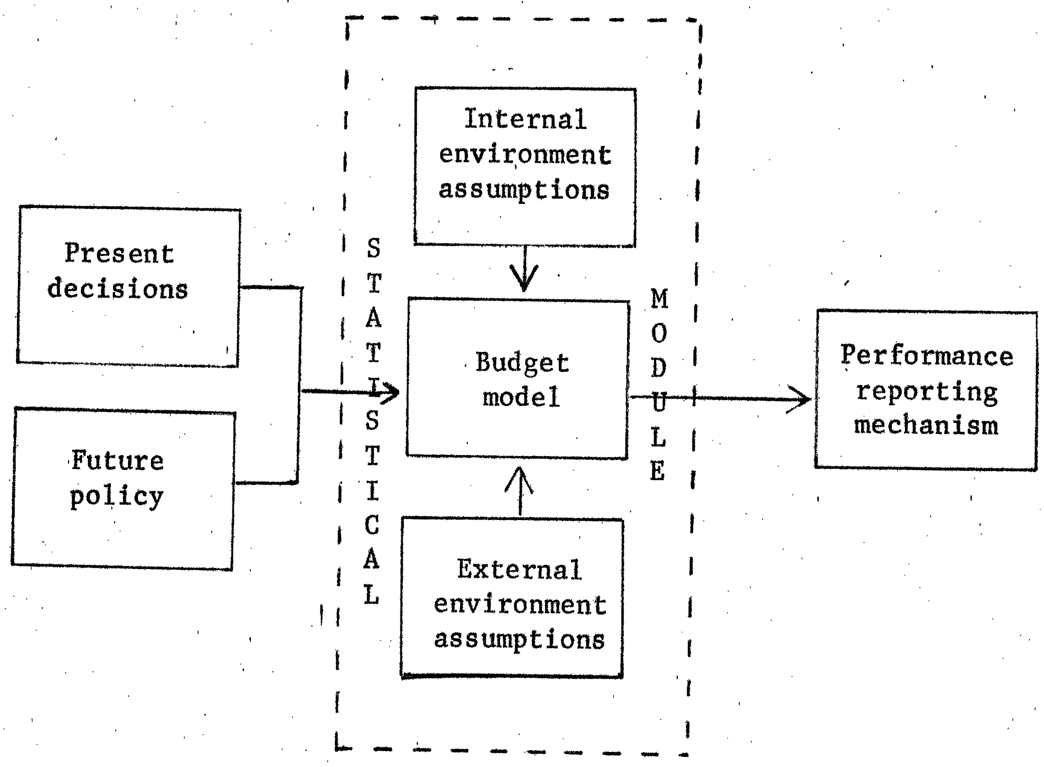

Fig. 4.

A logical advancement to the existing capabilities would be to introduce optimization techniques. The availability of optimization programs would, of course, be a source of additional decision alternatives.

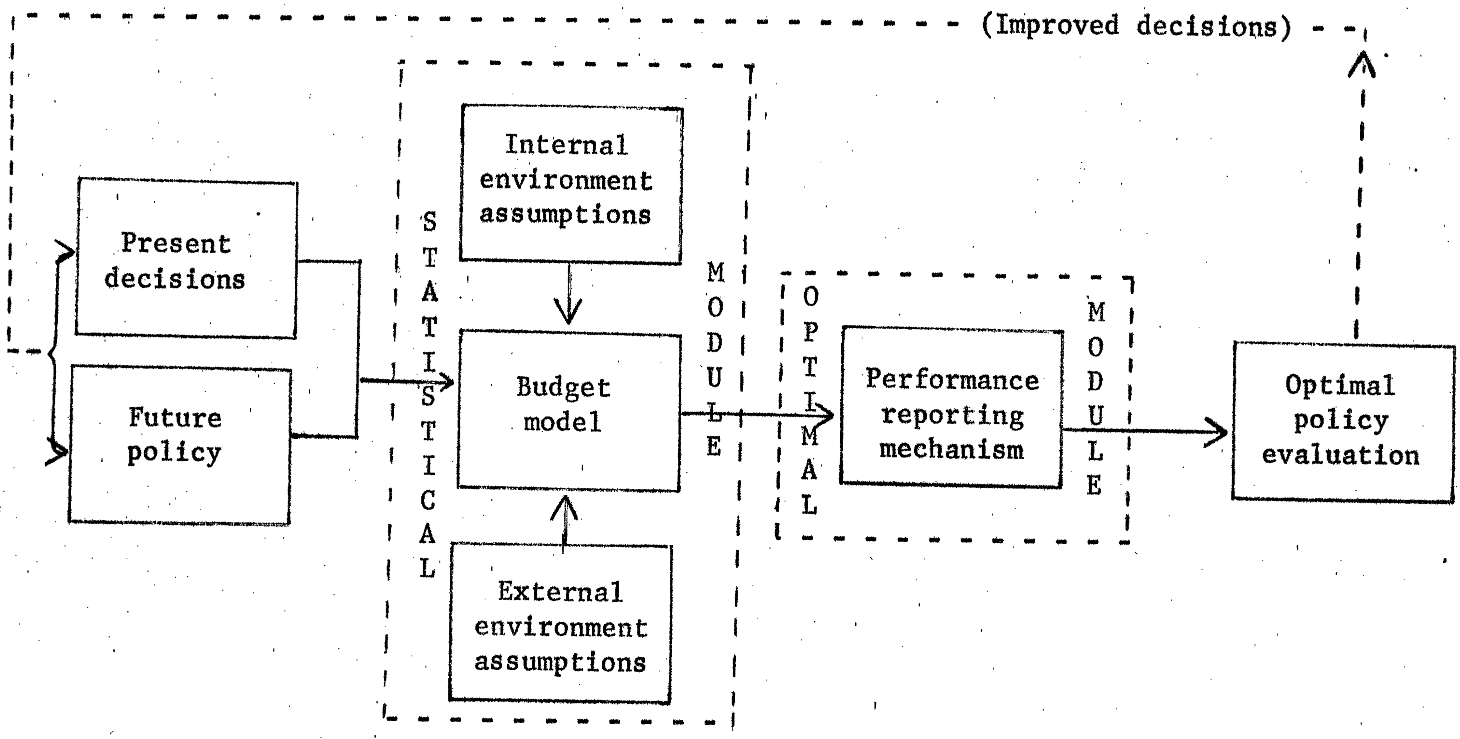

Fig. 5.

User involvement in model development and design will be further enhanced by the evolution of computer languages that enable one to construct mathematical systems. Important advancements have been made in the area of computer dialects tailored to the needs of model builders. Increasingly these dialects reflect management's jargon and the idiosyncrasies of the user. Such techniques can enable managers more readily to participate in constructing model specifications.

<u>Summary</u>

The extent to which a model will be used is, in large part, a function of the extent to which the user feels it adequately represents his environment. By affecting the learning process and the level of user involvement in model development, terminal systems will have an impact on the veracity of the computational system in the user's eyes. His increased faith in the system will be likely to result in his increased use of formal models.

IV

DATA BASE DESIGN

An implication of the integration of formal models into a decision-making unit is that the information system supporting that unit must be structured so as to meet the data requirements of the models employed. A barrier for most organizations attempting to employ mathematical models has been the inadequacy of internal data bases to provide sufficient amounts and adequate quality of data. Neil Churchill and Andrew Stedry have pointed out that data generated from existing accounting information systems may be inadequate where sophisticated planning techniques are available, particularly in terms of parameter estimation.[5]

There are two important sets of data bases within any organization. One is made up of a formal file structure, the other is stored within the human information structure.

Online systems are widely used to supply direct access to those files stored in a computer system--one part of the organization's formal file structure. In a similar sense, a terminal system has direct access to a user's memory. A properly constructed dialogue can be the basis for obtaining needed data by means of the intuitive estimates of the user. The system can help the user in his efforts as a data generator by, among other things, the immediate testing of the validity of his estimates. The trial-and-error search between man and terminal-based models in the systems studied was an important source of data, particularly in terms of the estimates of probabilities. In such systems, the user was also responsible for dealing with the possible lack of independence among variable values.

The developers of a probabilistic information system which was studied gave a great deal of credit for the success of the system to the fact that it was terminal based. They pointed out the convenience and cost-saving factors related to such systems. The structure also enabled the developers to more readily access data bases stored within the human information structure and to use this corporate resource in overcoming the inadequacies of formal data bases.

Given that managers are typically men who are heavily involved in the relevant problem-solving areas, employing a human in a system used to develop and maintain data bases is not unreasonable. It is interesting to note that research carried on at the University of Michigan has shown that decision makers are capable of estimating conditional probabilities with accuracy sufficient enough to serve as a basis for decision making.[6/]

An illustrative example of employing online capabilities for parameter estimation is given in a paper by Glenn Urban.[7/] Urban suggests that relationships which may not be estimable with existing econometric techniques can be derived by using a trial-and-error search routine through a remote terminal. He points out that this methodology would not be applicable in a batch-processing system.

Terminal systems can further assist a user in overcoming possible deficiencies in internal data bases by offering direct access to external data bases. Any number of commercially developed and maintained data bases covering a wide spectrum of activities are available on a direct-access basis to users who might otherwise find the data unavailable.

In the evolving computational architecture, terminal-based models are likely to be online with at least two data bases: the formally structured, internal data bases within the computer information structure; and at least as important, if not more important, the data stored within the human information structure. In a terminal mode the latter is merely another example of how man's intuitive capabilities have been effectively welded to mathematical models.

V

THE HEURISTIC ELEMENT IN MODEL SYSTEMS

Full information about a problem lies outside mathematical models and data bases. An advantage of terminal systems is that they allow the decision maker's capabilities, such as pattern recognition and intuitive understandings, to be integrated into the computational operations in problem solving and problem formulation. Online systems offer a means by which the user can dictate his role in the computational architecture. The user's capacity to act as a data generator and further to modify variable definitions and relationships can add a new element of realism to models--the heuristic capabilities of the user. Judgment and intuition are used in designing the models, in deciding what alternatives to consider, what factors are relevant, what the interrelationships between these factors are, and what criteria to choose in interpreting the results of the analysis. This fact--that judgment and intuition permeate all the analysis--should be remembered when we examine the nature of terminal-based mathematical models.

All decision makers appreciate that models cannot take everything into account. This is particularly true in dealing with the nebulous, nonquantitative considerations. Those aspects of a terminal environment which can be described formally are incorporated into the computer model and readily coupled with management's appreciation of its own environment. The heuristic-analytic loop in a terminal system provides the opportunity for the trial-and-error accumulative learning which is applied in successive steps in problem solving. In this environment, problems are redefined and decision rules re-evaluated and restructured in new decision model alternatives.

One effect of such changes is likely to be a move toward greater use of those models which emphasize cognitive processes in decision making. Such models will be characterized by a set of single decisions in which each decision attempts to improve the outcome in view of new information gained in previous decisions. Man is fairly well suited for this modeling role in that he can recognize patterns quickly and recall information through association and learning. Another effect will be to move decision makers along a spectrum from no formal search to a good deal of nonprogrammed formal search.

The economics of terminal systems permit, in fact encourage, the search process. The human's role is largely one of generating and evaluating various alternatives. The computer carries on the necessary calculations.

In existing systems the effectiveness of the search process is largely a function of the user's ability to apply subtle heuristics. The role of man is limited somewhat by his inabilities to consider large numbers of variables tied together by ill-structured relationships. As search processes become increasingly complex, users will undoubtedly seek to formalize search strategy in order to increase the efficiency of their decision making.

Regression analysis has been used in some systems to formalize an aspect of the search process. An online budgeting system employed this statistical technique as a basis for determining the opening gambit for search. This was done by generating information on an initial set of variable values. From the initial point on, the user would apply heuristics.

The user's problem is to draw from the data bases available to him a constellation of variables that somehow determine the state or outcome of the variables under review. Very often the isolation of these clusters will enable the user to postulate a general set of factors which determines much of the phenomena with which he is concerned. By using regression analysis the user is better able to deal with a set of environmental variables and relationships in attempting to gain knowledge about the effect of alternative courses of action.

In the case of the budget system studied, econometric relations were used to relate certain key variable values to project period financial statements. At each period the user could display the then-current financial statements and make new decisions which might override those established through the regression analysis. This procedure is repeated until he has stepped to the end of the planning horizon.

The product is a sequence of statements over the planning horizon. Based on his analysis of this output, the user might decide to modify certain of his assumed decisions. He could then repeat the sequence of steps and create a new set of projected financial statements.

Through discussions with users of such systems it was determined that, in the resultant analysis of the budget by a review committee, both the most likely set of variable values and the nature of the search involved in generating them came under scrutiny. The users who were questioned exhibited a concern for introducing techniques within the system that could assist them in their search process--a set of procedures that would help them in both communicating and justifying their search process.

This is not surprising, in that acknowledging search requires an explanation of how it is considered in making a decision. Lacking such a plan for explicitly considering search could force the decision maker to resort back to procedures that ignored search in a formal sense.

In examples such as online budgeting, the human, in performing online prognostic and diagnostic work, is likely to concern himself with a relatively small set of variable values in terms of the total relevant set. He may rely on some type of quantitative analysis to establish relationships that are not of immediate concern to him. Having defined his "relevant" set of variables, it is conceivable that the user could then rely on formalized search techniques such as hill-climbing optimization, in order to determine the complex relationships between the variables and the set of variable values that maximize his objective function.

Some rather complex search processes were observed within the terminal systems considered. One example involved search along a multidimensional response surface. This type of search is common in those decision areas in which negotiations involving at least two objective functions and a set of constraints are carried out. A particular example of the use of direct-access systems in this area is multi-user cooperation in problem solving through a single model. It is possible that such cooperation could eliminate suboptimality beyond that which is possible within existing computer information systems.[8/] The suboptimality in this case is brought on by the disaggregation of decision areas which are not independent of each other.

As search processes become increasingly more complex, the human will need the assistance of a master search plan or strategy that combines achievement with exploration. The search strategies which may be introduced into the system will define an important aspect of the data requirements of terminal decision units. The following comment by C. Churchman is of relevance in considering the importance of search strategies in a terminal environment:

> The rich technology of mathematics and logic permits us to lay out alternatives in a very implicit way. However, there is little technology that guides the manager in the selection of relatively new alternatives or in the consideration of the alternatives of the larger system.[9/]

VI

IMPACT ON INFORMATION REQUIREMENTS

By creating an environment in which a user can more readily incorporate mathematical models into his decision processes, terminal systems will influence the information needs of decision units. In this section some general observations are made as to the type of transformations that might occur in an organization's information environment.

A model determines, in large part, the information a manager can use, and the model itself has data requirements which must be met. Models can allow a user to deal more effectively with a large set of variables. In existing information systems the amount of data compression is commensurate with the limitations of man. In a terminal environment in which the decision unit can readily deal with a large set of variables, it is likely that lower level variables may obtain a position of relevance not found in a nonterminal environment. Reducing the extent of data compression in an information system is also one possible means of expanding data bases in order to meet the data requirements of various quantitative techniques.

Another interesting example of the data requirements related to model usage is in the area of control. In conventional systems, the only organized information available about deviations usually relates to total deviations. In the case of terminal-based planning units in which models are likely to play an integral part, not only should predicted outcome variables be compared with corresponding actual variables, but the planning model itself should also be subject to the same sort of control. It will be necessary to break down the total deviation in order to establish those deviations due to errors in the model.[10/]

An additional transformation in the information environment will arise from the influence of terminal systems on the types of models used within an organization. One such transformation is that from verbal models to mathematical models. Other important trends identified within the latter set include moves toward models which emphasize the cognitive strengths of the human and moves from deterministic to probabilistic types of models.

The rationale, in part, for developing formal models is to expand the decision maker's ability to search through alternative courses of action. Given the extent to which terminal decision units make use of mathematical models, it is not too surprising to find formal search playing an important role in their decision-making processes. In turn, however, the terminal decision unit will need data generated both to stimulate and guide the search process.

The non-human element of the system must also act as a "trouble shooter," whereby it acts to support a decision maker in the development and use of terminal-based mathematical models. The system must have the capabilities of meeting the user's information needs in terms of (1) answering questions, (2) evaluating recommendations, and (3) assisting decision makers who are having trouble either answering questions or recommending appropriate responses.

A designer of the next generation of information systems must consider the data needs related to the functioning of various algorithmic techniques which are likely to be integrated into the operations of terminal decision units. This is necessary, not only to ensure an effective interface between the human and formal models, but also to establish system requirements related to the development and maintenance of organizational data bases. These specific data needs of terminal decision units will differ from their nonterminal counterparts in the sense that the nonterminal group does not, for the most part, employ the types of models characteristic of terminal decision units in their decision processes.

VII

CONCLUSIONS

The findings of this study suggest that terminal-based systems can offer a computational architecture which will affect both the extent to which formal mathematical models are used for problem solving within organizations as well as the types of models which are employed. The identification of these dynamics within organizational decision systems should be of critical importance to the designer of information systems in evaluating the relevance of existing and proposed accounting information systems in terms of the needs of terminal decision units.

Terminal systems can permit a manager to participate to a greater extent in the computational operant. Thus, in analyzing mathematical models, it is advisable not to consider them independently of a larger computational system. Within this framework it is possible to draw some meaningful comparisons between terminal- and nonterminal-based mathematical models. The findings of this study suggest that in a terminal environment there is likely to be:

1. Greater user involvement in the design and development of models

2. Model design which emphasizes the cognitive processes of the decision maker

3. Mathematical formulation characterized by increased modulability

4. Mathematical models designed to facilitate multiple-user cooperation in problem solving

5. A move toward greater use of probabilistic systems.

FOOTNOTES

1/See, for example, Michael S. Morton, Management Decision Systems: Computer-Based Support for Decision Making, Division of Research, Graduate School of Business Administration, Harvard University, 1971.

2/Heuristic decision making may be viewed as that type which does not readily appear to be highly programmable. It is largely built on intuition and not rigorous proof.

3/W. Allen Spivey and Robert M. Thrall, Linear Optimization (New York: Holt, Rinehart & Winston, Inc., 1970), p. 17.

4/The terminal model used to generate this example is the Cypher-PLAN system which is available through the Cyphernetics Corporation of Ann Arbor, Michigan.

5/Neil C. Churchill and Andrew C. Stedry, "Some Developments in Management Science and Information Systems with Respect to Measurement in Accounting," in Research in Accounting Measurement, edited by Robert K. Jaedicke, Yuji Ijiri, and Oswald Nielsen (Evanston, Illinois: American Accounting Association, 1966).

6/Ward Edwards, Lawrence D. Phillips, and William L. Hayes, "Probabilistic Information Processing Systems: Design and Evaluation," IEEE Transactions on Systems Science and Cybernetics, SSC-4 (Sept. 1968), p. 250.

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9/C. West Churchman, The Systems Approach (New York: Delacorte Press, 1968), p. 92.

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