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MANAGING GROWTH AND CHANGE IN AND R&D ORGANIZATION:
THE ROLE OF DYNAMIC MODELING

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ABSTRACT

A systems dynamic model of its R&D organization has been developed by Battelle-Northwest to serve as a basis for improved management planning and policy making. This model was designed to be applied in an interactive man-model environment. Thus far, the model has proven useful in forecasting future resource demands under various contingencies; in providing a framework for discussion and analysis of the impact of management policies and decisions; and, importantly, it has improved managements' understanding of the structure and dynamics of their organizational environment.

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MANAGING GROWTH AND CHANGE ^{AND} R&D ORGANIZATION!

SYSTEM DYNAMICS MODELING FOR R&D MANAGEMENT

THE ROLE OF DYNAMIC MODELING

INTRODUCTION

The complexity and uncertainty of research and development has frustrated many attempts at quantifying the management process and forecasting the effects of growth and change in R&D organizations. The environment of these organizations is a very complex set of systems that interact with one another and also with an external world. Because of this complexity, management understanding of the impact of its decisions and policies is often nebulous at best.

^{Nevertheless,} ~~While~~ management planning and policy making ^{continues, although} ~~goes on nonetheless~~, the frequent practice is to concentrate on individual problems without regard to the rest of the system. The limitations of this practice have been widely discussed in the literature and have served as the *raison d'être* for applying a systems approach to management. Yet, even if management subscribes to the systems concept, the problem remains of determining ^{which} ~~what~~ approach ^{would be most useful} to understanding a system, is ~~most useful~~.

^{should not be} The effort required to identify and measure all the parameters affecting system operation ^{IS GENERALLY INFEASIBLE -- IS NOT POSSIBLE} ~~are often arduous and time consuming in the extreme~~. It is possible, however, to attempt approximation simulations as a first step in learning more about the parameters and system interactions. Despite the gross nature of the preliminary approximations, experience suggests that a ^{considerable} ~~good deal~~ of insight can be realized from a rigorous examination of the assumptions and results of the initial approximations. ^{and} ~~This~~ insight can result in the introduction of significant refinements in later models. Continued iterations of this approach can net a useful degree of realism and understanding of the fundamental dynamics of, ~~in this case~~, the R&D management system.

The problem facing R&D managers entails simultaneous consideration and control of a variety of processes. These include the research mix, manpower levels which should be maintained, equipment, facilities requirements, and numerous forms of decision making. Each of these processes is influenced by a multitude of other factors. The failure of previous research to support many simple cause-and-effect relationships suggests that strong interdependencies exist not only among multiple causes, but also between causes and their multiple effects.

At Battelle there is increasing management recognition of the need for improved understanding of the effects of various management decisions on the organization and its operations. In particular, there is a perceived need for better and more accurate forecasts of manpower and spatial demands so that management can better plan for growth and so that allocation decisions can be made on a more rational basis.

This paper reports on research conducted at Battelle-Northwest toward developing a system dynamics model of its research and development organization to serve as a basis for improved management planning and policy making. Particular emphasis was given to the need for this model to be usable in an interactive man-model environment. It was determined that maximum benefit from this application could be realized only if management personnel became an integral part of the model operation, as well as development.

MODEL DEVELOPMENT

The data and assumptions upon which model formulation was based were obtained from the records of a laboratory operation and from interviews with its management. Regression techniques were used to test causal hypotheses and to formulate an initial concept of the system and the various subsystems. This helped in later developing the general form of equations and the feedbacks that should exist in the model. The equations are mathematical descriptions of the operation of the system and are in the form of expressions for levels of various types which change at rates controlled by decision functions. The level equations represent accumulations within the system of such variables as research volume, personnel, facilities, etc., and the rate equations control the change of the levels with time. The decision functions represent either implicit or explicit policies established for the system operation.

Model development followed the iterative procedure illustrated in Figure 1. The model was initially constructed based on analysis of historical data and management's perception of system structure and mechanism of system operation. The model was then tested against the historical performance of the system. If variances resulted, sensitivity analyses were conducted to indicate the controlling variables in the model, and revisions were made in the model formulation until acceptable agreement was obtained between past system performance and model predictions.

The model which resulted describes the conversion of research contract sales into staff and spatial requirements, research backlog, volume of research, staff hiring and firing demands, and spatial crowding factors. Throughout the model structure, there are points where the specification of various management policies are input. Thus the outputs of the model not only demonstrate response to sales input but also to the type of management policies which have been specified.

~~CONCEPTUAL MODEL~~ ^{CONCEPTUAL MODEL} ~~STRUCTURE AND DYNAMICS~~ ^{STRUCTURE AND DYNAMICS}

Enter, all caps

The conceptual model ^{DEVELOPED} that resulted from these efforts is shown in Figure 2. The initial input is sales data, both actual and forecasts.

The model is ~~to be~~ run for a five-year period in time increments of one week. As a continuing validity check, the first two years are compared with two years of actual data gathered from accounting records, the landlord's report, and personnel records. The final three years represent forecasts of research volume costed (RVC), exempt manpower levels, non-exempt manpower levels, and space requirements. These forecasts are based on a department's sales projections for the final three years and actual sales estimates constructed from the first two years of accounting data.

The sales estimates flow into the research backlog at specific times. This increases the backlog of research and exerts pressures on the production rate to increase in order to complete the research according to a predetermined plan. Production rate ^{OPERATES AS} is not only a function of backlog pressures, ^{AS WELL} it ^{AS} must also depend on the level of manpower on hand and the facilities available.

The maximum productivity per person is determined by a functional relationship of the space required and the space currently available. The production rate is then determined as dollars of RVC flowing from the backlog to the completed research. This completes the research subsystem which simulates the aggregate research effort for a given department.

The manpower subsystem is responsible for maintaining the work force necessary to complete the desired research. This subsystem makes two major decisions involving the hiring rate and the manpower reduction rate. These decisions are dependent on the current work force and the level of output that the research subsystem ^{REQUIRES} ~~desires~~. For example, as sales increase, the backlog increases and pressures are exerted to increase the production rate. This increase in production will require the research per person to increase. If the research per person rises above set limits, there will be a demand for increasing the work force. Since, in reality, the manpower subsystem cannot respond to pressures instantaneously, a first order exponential time delay was incorporated to determine the actual hiring and production rates.

The number of people ~~then~~ determines the space required for those people as a function of standard spatial requirements. ~~(The spatial requirements per person were developed from historical data using multiple linear regression techniques.)~~ The facilities subsystem then ^{calculates} ~~determines~~ the demand for various types of facilities based on the current level of those facilities and the requirements imposed by the work force. This demand can be either positive or negative depending on whether the work force is increasing or decreasing. There is also a time delay in this subsystem because space cannot be physically added or subtracted from the existing facilities instantaneously.

The model was validated using two basic approaches. First, model parameters were constructed in a form consistent with management's own model of structure, operations, policies, and decision rules. Where appropriate data were available, these perceptions were tested using regression analysis to develop comparative coefficients. Second, the model was tested for fit against 20 months of historical operations. The final model structure was generally consistent with management perceptions; and its dynamics closely matched ^{those} ~~the dynamics~~ of actual operations.

4. Model Operation

Real-time

MODEL (Actual, operation)

Center all caps

A prime consideration during both the model development and ~~model computer~~ implementation was that the ~~model computer~~ package should be able to directly communicate with the ~~management~~ environment. During the model definition, ~~all coefficients and variables were quantities readily available in the current management information.~~ In addition to these physical types of parameters, all decision points are analogous to some real world control function. ~~THE COMMUNICATION CYCLE IS DIAGRAMMED IN FIGURE 3.~~

The visual graphics display ~~gives~~ ^{provides} an instantaneous and continuous graphical picture of the status of current model variables. ~~This function not only graphically shows the time distribution of the model variables, but also the time response.~~ This type of visual output allows the user to become very "involved" in the analysis loop and ~~enhances his intuitive and interpretive thinking.~~ ^{enhances his intuition and analytical capability}

Figure

BNW performs research for two major types of sponsors, identified in the model as 1830 and 1831. While the same basic policies of BNW apply to both ~~types of sponsors~~ and both use the same manpower and facilities resources, they operate under different decision rules and constraints. The model contains unique parameters for each, which allows each business model to be modified and exercised as required, independent of the other. There are additional model parameters that are common to both research types. The models for both 1830 and 1831 are basically identical in structure with regard to the flow of model variables. They do differ in the parameters which are used to direct the internal model decisions.

An important aspect of this model is that the conversion of one resource into another does not continue at a constant rate during the analysis. The rate of conversion changes throughout depending on the decisions made. These decisions are based on goals which are modeled. The user defines the importance and the limits and magnitude of these goals with model coefficients. He cannot, however, alter the form of the goal.

Center, all caps

5.6

APPLICATION

The model is being used as a basis from which to build a better, more concrete understanding of the entire BNW business system. Thus far, management has experienced two major impacts from interacting with the model. First, interaction with the model's structure and the match with historical data have served to increase the credibility of ~~the~~ forecasts. Second, management has observed ^{CERTAIN} counter-intuitive results from the model in response to their trial goals and policies. Such results have caused them to reconsider their own intuitive models and to ask searching questions about the function of certain system components, ~~AS WELL AS THE STRUCTURE OF THE MODEL ITSELF. THIS PROCESS OF EVALUATION, QUESTIONING, AND REEVALUATION IS PERCEIVED AS A USEFUL EXERCISE WHICH SHOULD HELP TO IMPROVE THE MODEL OVER TIME.~~ ^{CONTRIBUTED} ~~THE~~ model has thus provided three important services to management. It has provided forecasts of future resource demands ^{UNDER VARIOUS CONTINGENCIES}. It has provided a framework for discussion and analysis of the impact of management policies and decisions. ~~Finally,~~ ^{AND} ~~THE~~ management has been able to improve its understanding of the internal structure ^{AND DYNAMICS} of its ^{ORGANIZATION} environment. ~~CERTAIN EFFECTS ARE BEING DIRECTED TOWARD EXPANDING AND REFINING THE MODEL.~~

REFERENCES

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B. N. W. BIOLOGY DEPT SPACE MODEL

Figure 2. Model Structure