ROLES FOR SIMULATION IN BEHAVIORAL RESEARCH

ABSTRACT

Simulation models have been used in a variety of ways for behavioral research. This paper discusses appropriate and inappropriate roles for the technique in such research.

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Introduction

For more than fifteen years researchers have been using simulation models to help analyze human behavior, and over that period the uses of the technique have varied widely. In many cases, the application of simulation to behavioral problems has not been very successful. The objective of this paper is to identify some of the research situations where simulation can and cannot be usefully used in behavioral research.

There are many kinds of problems with which systems analysts concern themselves that involve human behavior. But not all of them can be classifed as behavioral problems in the true sense. It will be shown that the appropriate role for simulation in systems research depends on whether or not a problem requires behavioral research. Before doing so, however, it is necessary to make explicit the difference between various kinds of systems problems that involve behavioral variables.

Types of Behavioral Systems

It is not true that all system analysis problems for which human behavior is an element in the system are behavioral problems. However, all behavioral problems do have human behavior as a systems element. Thus, the actions of people are a necessary but not a sufficient condition for classifying a problem as behavioral. The critical sufficient condition relates to which aspects of the system are assumed to produce a change in the behavior of the human elements of the system. Specifically, a behavioral problem in which two conditions exist: (1) a change in one or more of the systems controllable factors will yield a change in the behavior of one or more human element of the system and (2) this behavioral change in turn yields a different performance outcome for the system as a whole. Symbolically the conditions are:

$$P = f\ (H_i;\ U_j;\ C_k) \qquad 1$$

$$i = 1 \ldots m$$
$$j = 1 \ldots n$$
$$k = 1 \ldots o$$

and for at least one (i, k) pair

$$H_i = g\ (C_k) \qquad 2$$

where

P – measure of system's performance that is trying to be improved

H_i – behavior of individual i in the system

U_i – level of uncontrollable element j in the system

C_i – level of controllable decision variable k in the system

An example of a behavioral problem would be a company's efforts to increase its profits (P) by increasing purchasing behavior of customers (H_i) through revised advertising strategy (C_k) subject to competitor strategies (U_i).

A non-behavioral problem with human elements in the system is one where the human actions are assumed to be independent of the decision-maker's controllable elements. Thus, for example, if a supermarket assumed the rate of arrival of customers at its check-out counters were independent of the number of counters available, the problem of determining the optimum number of counters becomes a non-behavioral problem with human elements in the system. It should be noted that the method of solving the supermarket check-out problem, namely via Queueling Theory Models, requires that the human behavior be treated in the aggregate and analyzed as part of a probability distribution. The individual elements of the distribution could have been generated just as easily from non-human sources, as they in fact are in waiting-line analysis of automated production processes, and the conclusions would have been just as valid.

A fundamental difference between the analysis of behavioral systems and the analysis of behavioral factors in non-behavioral systems is the method by which the behavior is itself represented in models of the process. In a non-behavioral system, research interests only require that the patterns of overt behavioral responses be accurately described in the models. Such analytic descriptions are then summarized in terms of the frequency that each behavior pattern is observed to occur. These frequencies are then translated into probability distributions and integrated into a model that reproduces the behavior of the overall system. This method of representing behavior has been commonly used in marketing problems in which Markovian Transition Matrices are used to describe the probability of a consumer's next brand purchase based on his most recent brand selection.

Descriptive methods of representing human activities are appropriate as long as the problem can be formulated as non-behavioral; that is, Equation 2 above does not apply. In a behavioral problem, controllable variables in the system are assumed to cause a change in human behavior. Under these conditions description is not sufficient. Instead the research must lead to an explanation of the behavior. To achieve this, analysis of the system must go beyond the development of statistical frequencies of various kinds of action; it must first identify the purposes of the behavior itself, and second show how the levels of controllable variables in the system affect the purposes, and consequently the actions of people in the system. This means the research must lead to an understanding of how the systems environment affects the individuals in it, as well as how the individuals affect the system. Non-behavioral systems analysis is only concerned with the latter issue.

There is an obvious compatability between the capabilities of simulation techniques and the structural requirements of non-behavioral systems analysis; both emphasize statistical frequency fuctions as a language for describing the dynamics of the system. Such language compatability is not present in modelling behavioral systems. The research methodologies being developed in the Behavioral Sciences are becoming increasingly focused on identifying which environmental and personality factors are relevant -- and equally important which are irrelevant -- as causal factors in human decision processes. For such research objectives, statistical descriptions of behavior are inappropriate and are used only to represent aspects of the behavior for which no satisfactory explanation currently exists. The greater the need to rely on such descriptive representations, the smaller the researcher's understanding of the behavior. Thus, as behavioral research techniques become more sophistocated, the models that are produced are likely to be less and less similar to the standard simulation model format.

The appropriate long-run role for simulation in modelling human behavior will not be known until we are more clearly able to see the structure that behavioral models will ultimately take. Some trends are already bebinning to develop, however, and these shed some light on what can be expected. The trends can be brought out more clearly through an example of systems research on a behavioral problem. The example is particularly appropriate because "traditional" simulation models were developed for part of the analysis. These models subsequently were discarded as being incompatable with the ultimately research objectives, and a revised research program was established. As this program was implemented, a more appropriate role for simulation was articulated.

ANALYSIS OF HUMAN BEHAVIOR IN CONFLICT SITUATIONS

The objectives of the research program was to develop quantitative models that provided an explanation of how people behaved when placed in a conflict-inducing situation. The research was carried out by the Management and Behavioral Science Center of the University of Pennsylvania, and was sponsored by the United States Arms Control and Disarmament Agency. The general strategy was to use quantitative model building techniques to analyze the dynamics of the escalation and deescalation of conflict. The hope was to identify general behavior patterns in conflict situations that might have implications on the best policies for controlling such conflicts. The study was carried out over a five year period, which provided the research team with substantial feedback on the viability of different methods for conducting behavioral analyses. Consequently, the research methodology was revised and refined several times during the project's duration.

One advantage of the broad charter of the research program was that much of the model building could take place based on the analysis of human behavior in laboratory conflict games, a number of which have been constructed as analogies to the situations a person might face in a real world conflict. One of the games most often used for this purpose, and one which was extensively used for our own research, is known as the Prisoner's Dilemma. This is a two person, non-zero-sum game in which each player has only two possible choices. The choices are usually termed cooperation (C) and defection (D). An example of a typical Prisoner's Dilemma game is shown in Figure 1. The entries in each cell of the matrix are the payoffs to Player A and Player B respectively, and are the outcome of the simultaneous and independent decisions of the two players to cooperate or compete. The properties of the game are such that, from an individual point of view, it is to each player's advantage to always defect; that is, if the second player cooperates it is to the first player's advantage to defect, and if the second player defects it is still to the advantage of the first player to defect. However, it is an additional property of the game that when both players defect they arrive at a payoff condition where each would agree that another joint strategy, namely both cooperate, yields a jointly superior solution.

The Prisoner's Dilemma game has been used extensively as a research tool to study human behavior in conflict situation. Most researchers collect data by having two subjects play repeated trials of the game against an unknown opponent, with a monetary reward to each participant that is proportional to the number of points he accumulates during the game. Rapaport (1965) has done extensive experimental work on the Prisoner's Dilemma. One of the results he has found is that the proportion of cooperative moves made by a subject during the game tends to decrease for some period of time and then slowly rise to a stable level of about 70% cooperation. This pattern is shown in Figure 2. Not only is the Prisoner's Dilemma a rich research environment because subjects tend to learn different behavior patterns over the course of their play, but different people tend to behave quite differently in the same game. For example, Rapoport found that females tend to play less cooperatively over the course of the entire game than do males.

In the process of reseach a large number of controlled laboratory conflict experiments were conducted using many different game environments. Initially, research was concentrated on the Prisoner's Dilemma game, not only because it had the most extensive reported literature of any conflict game, but also because it was the simplest possible conflict environment one could structure -- namely two persons, each of whom has only two choices. To gain some experience with the game, a number of Prisoner's Dilemma conflict games were run in which the subjects were interviewed during and after the game. These interviews provided information on the strategies subject claimed to be using, as well as an indication of how these were modified during the course of play. When a fairly wide range of strategies had been articulated, a simulation model of the game was built to see if it was possible to reproduce the behavior pattern that had been found to occur over the actual game playing situations. This was the simulation which was subsequently discarded in favor of a revised research methodology. Before discussing revised methodology, a summary of the characteristics of the simulation model itself will be presented. This will highlight the weaknesses of applying standard simulation methodology to behavioral problems.

A SIMULATION MODEL OF CONFLICT BEHAVIOR

A flow chart of the model is shown in Figure 3. A complete description of the model and its output is presented in Emshoff (1970). There are four parameters in the model, and each is meant to describe an individual personality characteristic of the player whose behavior is being simulated. The four parameters are: Memory, Foresight, Competitiveness, and Rigidity. The critical assumption in the model is that all players made each of their decisions in the game so as to maximize some specified utility function, the exact nature of the function being determined by the specific parameters values for the individual. For example, the interviews indicated many of the subjects had objectives in the game other than the stated one of maximizing individual resource position at the end of it. Some subjects felt that it was important to beat the other player; others wanted to maximize the total resource position of the two subjects, independent of their own particular position. We tried to account for this phenomenon through the Competitive parameter, which represented the goal of the game as interpreted by each player. We also found players differed in the amount of game history they used in evaluating the strategies they thought their apponent might be using. Memory parameter was designed to account for this phenomenon. Similar special features of the game where there were indications that different subjects could have different interpretations were used to specify the function of the other two parameters. It should be emphasized, however, that regardless of the paramaters value, the basic assumption of the simulator was that all subject's actions were designed to maximize their individual utility functions.

By using a gradient search technique, we were able to fit the parameter values to different sets of game data. This enabled us to find the best combination of the four parameter values which reproduced the playing behavior of a specific subject in the actual game. These parameters were then attributed to be psychological characteristics of a particular individual playing the game. Based on data from twenty games, it was found that the simulation model could predict approximately 75 percent of the individual choice behavior correctly, Before proceeding to a validation stage, in which parameters would have been fit on part of data from a game and then used to predict play in the remainder of it, an effort was made to compare the 75 percent predictability with other "more nieve" models for predicting play. Somewhat to the dismay of the research team, a very simple model did better than the simulator. The model was that a player will play the same strategy as his apponent did on the previous play, a model referred to as "lagged tit-for-tat." This rule provided nearly a 80 percent predictability on the same data that the tremendously more complex simulation model had only been able to achieve a 75 percent level. The researchers concluded that the complex simulation model could not be justified until an explanation was provided for the success of the much simpler model. Intuitively, the research team felt the simulation model was preferable to the use of such a simple and mechanistic rule, but there certainly was no objective evidence to prove the contention.

The research team was never able to use the simulation model to explain why the simple lagged tit-for-tat rule worked so well, nor could the rule be meaningfully incorporated into the simulation structure. The primary reason for this situation was the method used to construct the simulator. It was structured as one integrated model, which could not be segmented and tested to determine which aspects were relevant and which weren't. It could easily have been made more complex, had that been the research problem, but simplification within the defined structure was difficult to achieve.

This problem led the research team to question the basic merits for using a simulation approach at such an early stage in the project. Clearly, the first research priority for the team was to identify which factors caused people to change their actions in the conflicts; that is, to identify relevant behavioral variables in the system. However, the most common use of simulation models has been in situations where relevant factors had already been identified and research interests centered on studying the performance of the system as it was affected by the joint interaction of all the factors. Thus, a simulator-oriented research strategy resulted in an analytic tool that confounded the task of identifying relevant variables with the task of analyzing interaction effects. This in turn led to the team's inability to resolve problems regarding the complex structure of the simulator itself.

As a consequence of this situation, the simulation strategy was abandoned and a revised research methodology was developed for the project. The objective was to build a model which could be revised and improved sequentially, with tests to ensure relevancy of factors in the model being conducted at each research stage. Experimentation became a key factor in the new research program. The Team was less concerned about the explicit form of the ultimate model -- simulation, mathematical, or analogue-- than that the model represented as well as reproduced the human decision processes. The implementation of this methodology provided a clearer focus of the appropriate role for simulation in the analysis of behavioral systems.

A STRATEGY FOR BEHAVIORAL RESEARCH

Partially as a result of the research team's experience with the simulation model, a set of assertions were developed about the characteristics of behavioral analysis. These assertions, which became cornerstones for the research strategy are:

1. It is easier to add a (potentially) relevant factor to an existing behavioral model than it is to identify an irrelevant factor already in the model.

2. Scientific progress is usually associated either with a reduction in the number of variables required for an explanation or in an equivalent explanation that has greater generality.

The research strategy was based on the parsimonious principle of trying to develop the least complex model that could explain some aspect of behavior in the system. Revisions and enrichment of the model should only be added when experimental tests have shown that the current one is inadequate.

There are four steps to the methodology for the conflict research:

1. A possible explanation of an individual's choice in the conflict situation was formulated. The explanation contained the unique properties of both the individual and the choice environment as independent variables, and the specific choice of the subject as the dependent variable.

2. Objective procedures were designed to measure the psychological variables in the explanation and, based on these measures, an exclusive and exhaustive classification of a subject's possible psychological status was formulated. This hypothetical explanation was then used to deduce which choice an individual would made in each possible state (i.e., a model constructed).

3. An experiment was designed and conducted to determine whether or not the deduced predictions were correct.

4. If the tests refuted the explanation, the model was modified in light of the results. Predictions were then derived from the revised explanation, and a new experiment was designed to test them. If the predictions were correct, a new environment was specified, new predictions were prepared and Step 1 of the sequence was begun again.

A flow chart of these procedures is presented in Figure 4. An important aspect of the research strategy was the effort to generalize the behavioral model whenever it failed to perform statisfactorily. Only through generalization would it be possible to avoid multiplying the complexity of the explanation whenever a failure occurred.

The success of the sequence of generalizations depends a great deal on strategy that is used for defining enlarging the behavioral system which is to be modelled. In the conflict research program, a three-phase strategy was used:

1. Develop a Static Perception Theory: Given a subject's predisposition just prior to his choice, predict what choice would be made.

2. Develop a Dynamic Learning Theory: Predict how a subject's predisposition would change as a result of actual experience in the conflict.

3. Develop a Dynamic Personality Theory: Predict how perceptions would be altered as a result of unique characteristics of the individual.

A detailed description of the development and refinement of the behavioral theories during the project is published elsewhere (Emshoff, 1971). They are not particularly relevant to this discussion. But the problems encountered in implementing various phases of the methodology are important, for they indicate the kinds of roles simulation is likely to play in future analyses of behavioral problems.

ROLES FOR SIMULATION IN BEHAVIORAL RESEARCH

In the early stages of the revised conflict research program, there was no need for simulation. Models were very simple -- only one or two variables -- and used straight-forward functional relationships to make predictions. Furthermore, the models underwent rapid and fundamental changes fairly frequently as a result of disconfrontation were the key characteristics.

After about a year of implementation of the research methodology, the model revisions rarely involved changing the fundamental structure. Experiments became increasingly specialized, testing hypotheses about behavior in specific situations. Although simulation was never made an explicit part of the new research strategy, it would have been a useful tool for many of the detailed experiments. Had the data from each experiment been fed on-line into a simulation model of the particular behavioral theory, researchers could have identified when the particular behavior of interest was occurring. This could have led to specialized experimental programs to more readily understand what was causing the observed behavior. Without on-line simulation techniques, analysis of experimental data was not carried out until well after the subjects had left the laboratory.

Another use of simulation that became apparent during our research was to control environmental conditions more closely, in order to create the situation that is of particular research interests. For example, in the conflict research it would have been possible to let a computer act as one of the participants in the conflict, with the simulation model providing the mechanism for choice behavior. Appropriately programmed, the computer could make decisions designed to force the real participants into a particular attitude which will cause him to behave in a way which is of research interest. Methods so designed to create conditions which are less likely to occur in unstructured experiments greatly increase the efficiency of experimental tests.

A final role for simulation that became apparent in the conflict research is one more closely associated with standard simulation applications. This is as a method for analyzing the interaction among the relevant factors in the system. As the conflict research was expanded to increasingly more complex problem definitions, the models became more sophistocated. As this happened, researchers were less able to see inherent incompatabilities between the hypotheses that were being formulated and those already in the model. By simulating behavior before testing the hypotheses experimentally, many such situations can be caught because of the illogical simulated behavior that results. This enables hypotheses to be reformulated before going to the time and expense of rejecting them through experimental testing.

Not all three uses of simulation just identified are likely to become standard applications will almost certainly be added. One thing that is almost certain to be true, however, is that simulation's role in behavioral research will seldom be at the early stages of the study. Too little is understood for that to be so.

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		Player B: C	Player B: D
Player A	C	10,10	-10,20
	D	20,-10	0,0

FIGURE 1. A TYPICAL PRISONER'S DILEMMA GAME

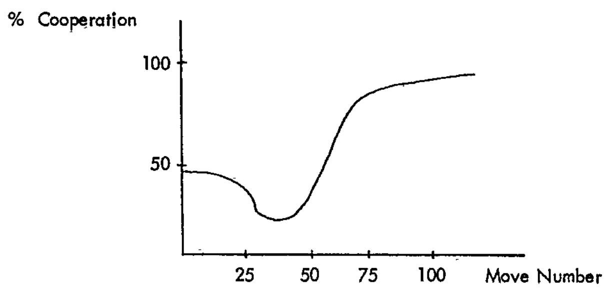

FIGURE 2. PATTERN OF COOPERATION DURING THE COURSE OF A PRISONER'S DILEMMA GAME

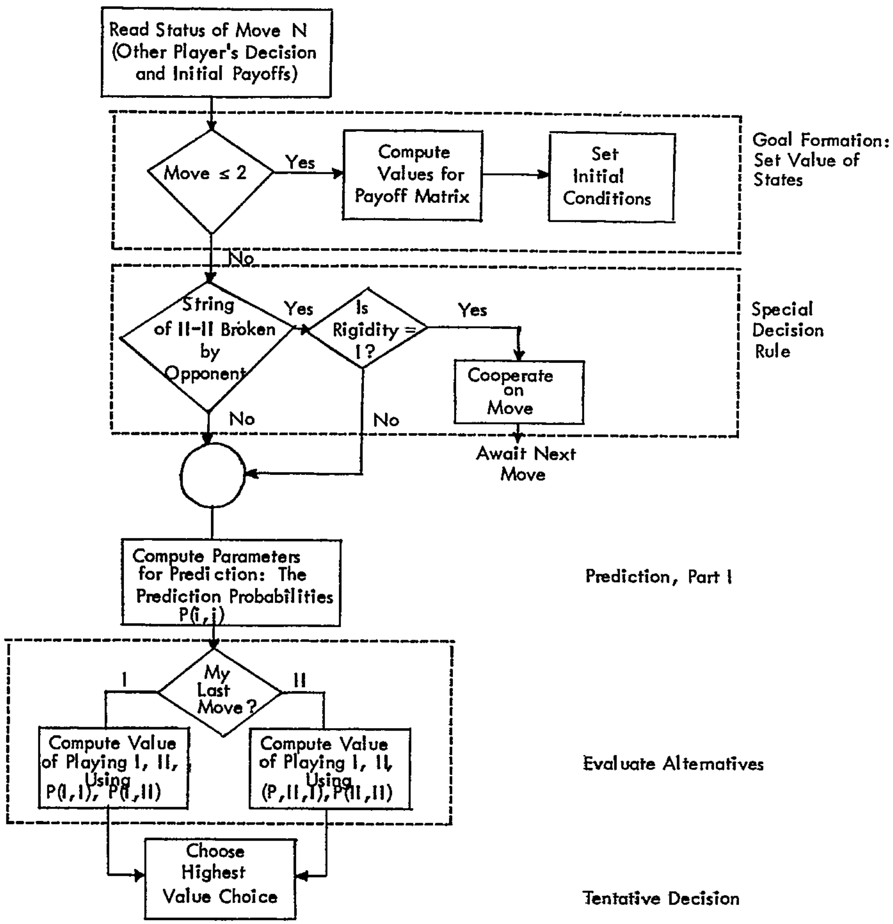

FIGURE 3 First Part

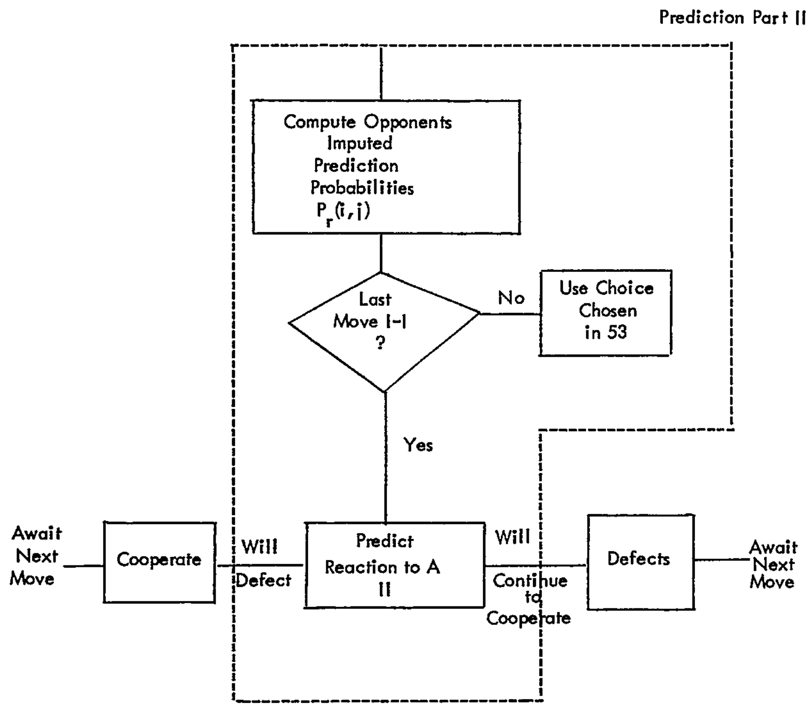

FIGURE 3 (continued) Flow Chart of the Simulation Model

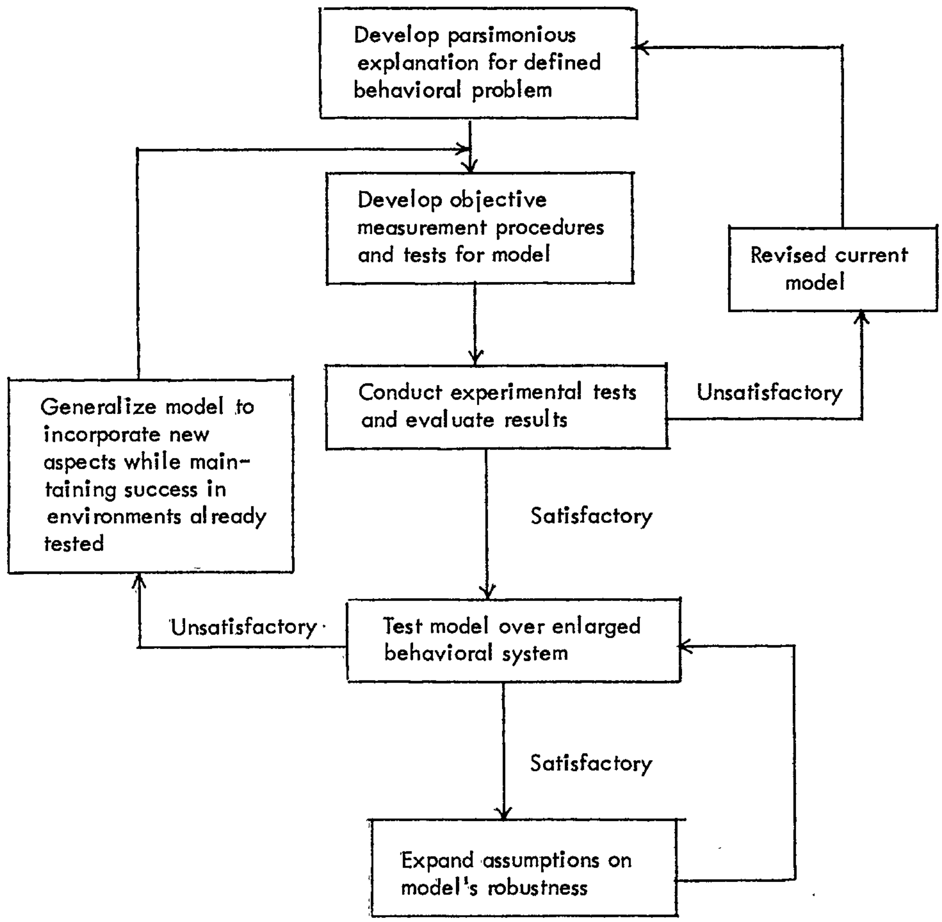

FIGURE 4 SEQUENTIAL BEHAVIORAL RESEARCH METHODOLOGY