AD A128641

Research Product 81-32

DIGITAL BEHAVIORAL SIMULATIONS
STATE-OF-THE-ART
AND IMPLICATIONS

TRAINING TECHNICAL AREA

June 1981

U.S. ARMY RESEARCH INSTITUTE for the BEHAVIORAL and SOCIAL SCIENCES

U. S. ARMY RESEARCH INSTITUTE
FOR THE BEHAVIORAL AND SOCIAL SCIENCES

A Field Operating Agency under the Jurisdiction of the Deputy Chief of Staff for Personnel

JOSEPH ZEIDNER
Technical Director

L. NEALE COSBY
Colonel, IN
Commander

Research accomplished
under contract to the Department of the Army

Applied Psychological Services, Inc.

NOTICES

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Research Product 81-32	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) DIGITAL BEHAVIORAL SIMULATION--STATE-OF-THE-ART AND IMPLICATIONS		5. TYPE OF REPORT & PERIOD COVERED Final Technical 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Arthur I. Siegel, J. Jay Wolf		8. CONTRACT OR GRANT NUMBER(s) MDA903-79-C-3013
9. PERFORMING ORGANIZATION NAME AND ADDRESS Applied Psychological Services Science Center Wayne, PA 19087		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 2Q162717A790 2Q263743A794
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Research Institute for the Behavioral and Social Sciences, 5001 Eisenhower Avenue, Alexandria, VA 22333		12. REPORT DATE June 1981 13. NUMBER OF PAGES 99
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Modeling
Simulation
Human Performance
NETMAN
System Analysis
Model Design Review

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents a comprehensive review, analysis, and appraisal of the state-of-the-art in computer simulation models in which human performance characteristics play an important part. Concepts and considerations important to the development of such models are discussed and examples of current models are presented to provide an overview of the status of the digital simulation field relative to behavioral simulation.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Item 20 (Continued)

Methods which have been or could be used in predicting and, or accounting for human effects in Army system performance are identified and defined. Problems in model design are treated and the trade-offs of cost versus benefit, which characterize the models and are associated with current models, are discussed. Future trends in behavioral modeling are also projected, along with recommendations relative to the development and maintenance of current Army models.

Research Product 81-32

DIGITAL BEHAVIORAL SIMULATIONS STATE-OF-THE-ART AND IMPLICATIONS

Arthur I. Siegel, J. Jay Wolf
Applied Psychological Services, Inc.

Submitted by:
John F. Hayes, Acting Chief
TRAINING TECHNICAL AREA

Approved by:
Milton S. Katz, Acting Director
TRAINING RESEARCH LABORATORY

U.S. ARMY RESEARCH INSTITUTE FOR THE BEHAVIORAL AND SOCIAL SCIENCES
5001 Eisenhower Avenue, Alexandria, Virginia 22333

Office, Deputy Chief of Staff for Personnel
Department of the Army

June 1981

Army Project Number 2Q162717A790 2Q263743A794	Human Performance Effectiveness and Simulation Education and Training

FOREWORD

The accurate simulation of human behavior in known situations provides increased ability to understand and to predict behavioral outcomes under unknown or hypothetical circumstances. Concepts and considerations important to the development of realistic predictive behavioral simulations are presented in this report to encourage the additional development of computer simulation techniques. The realism and predictive power of current Army system models could be sharply increased if human behavioral simulation were to be incorporated into these models.

Within this report, methods which have been used or could be used in accounting for and predicting human effects in Army system performance are identified. Problems in model design are treated and the costs and benefits which characterize a number of the models are discussed.

This report was compiled as a part of Army Project 2Q162717A790 and 2Q263743A794.

Joseph Zeidner

JOSEPH ZEIDNER
Technical Director

EXECUTIVE SUMMARY

Background and Problem

Human behavioral considerations are believed to be essential ingredients in Army planning. Yet, behavioral modeling through computer simulation techniques has been employed in only a limited number of Army computer simulation models.

The realism and the predictive power of current Army system models could be sharply increased if human behavioral simulation was incorporated into the system models. Limited prior experience in the Army suggests the advantage and potential of behavioral modeling.

Methods and Results

Behavioral simulation modeling, defined as a representation of behavior and behavioral influence implemented on a digital computer so as to allow control or prediction of an event or event sets, is reviewed. Current behavioral models are described in sufficient detail to allow some comprehension of the simulation detail and comprehensiveness currently available. Examples are given of behavioral simulations which might be incorporated into current Army computer simulation models. Pervasive problems in human behavioral simulation are reviewed and methods for meeting these problems are presented. These include such diverse issues as the type of model to construct, time and event advance techniques, input data requirements, data availability, required level of input data detail, choice of programming language, transportability, model validation, generality, the model-user interface, cost/effectiveness considerations, individual differences representation, and parameter estimation and choice.

Implications

An increase in the use of behavioral simulation relative to evaluation of the design and use of Army equipment systems and personnel subsystems seems warranted. To this end, available behavioral simulation modules should be tailored so that they can be employed to moderate the results from or to interact with equipment system models so as to produce output which considers the human component in the person-machine integral. New behavioral modules which are pertinent to the Army situation should also be developed along with the appropriate data base for supporting such modules. Such an effort should be systematic and provide immediate (short term), and mid term (about five years) end products. The work should be based on and drawn from a user needs/requirements survey which pinpoints the type of behavioral variables which are most salient to Army needs and the type of output required by the Army user.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont.)

LIST OF TABLES

LIST OF FIGURES

I. ROLE OF BEHAVIORAL MODELS

Introduction

Modeling of systems and events has emerged over the years as a fundamental tool for system evaluation. This report is concerned with a specific category of models--digital simulation models--and with a specific class of models within the digital simulation category--stochastic digital simulation models of human behavior.

Advantages of Behavioral Models

Stochastic simulation models of behavior have become possible, in part, because of the advent of the high-speed digital computer. The capability of the computer to perform a myriad of calculations in very short time periods along with its decision making capability makes possible the accomplishment of processes which heretofore were impractical if not impossible.

A second set of reasons for the increased emphasis on (i.e., advantages of) behaviorally oriented digital simulation models lies in their ability to allow simulations of systems and conditions which, if examined or tested directly would: (1) be dangerous when performed through physical simulation means, (2) be costly in terms of commitment of large numbers of people or of large quantities of equipment, and (3) require long periods of time (i.e., years) to set up and accomplish. Digital simulation also allows the capability for highlighting potential problems in an actual system which has not yet been implemented, or in a situation or set of conditions which has never occured in an implemented system.

Digital simulation of a person-machine system is also attractive when the actual system "is so fully occupied that experimentation with changes in equipment, personnel policy, or resource assignment rules may be impractical, expensive, dangerous, or unlawful" (Siegel & Wolf, 1969).

Finally, such models provide a useful methodological tool to those behavioral and engineering scientists who are involved with: (1) the quantification and enhancement of human capability and its inherent variability, and (2) the related issue of the contributions of human unreliability to total system unreliability.

Definitions of Models

Computer models have been variously defined. Examples of current definitions are:

> A computer simulation is a logical-mathematical representation of a concept, system, or operation programmed for solution on a high speed electronic computer (Martin, 1968).
>
> A simulation model can be defined as an abstraction of some real system that can be used for purposes of prediction and control (Naylor et al., 1966).
>
> ...form a picture of (the system's) behavior by sampling from all the ways it might behave (Kendell, 1968).
>
> The (simulation model) produces outputs resembling those observed in the real world, and inspires confidence that the real causal process has been accurately represented (Dutton and Starbuck, 1971).
>
> A simulation model is an operator that generates a set of variables X, given a set of variables Y, such that: (a) the sets X and Y represent characteristics of the referent situation, (b) the set X is indistinguishable with respect to an explicit criterion from the corresponding characteristics of the referent situation, and (c) the operator itself represents the causal process of the referent situation (Starbuck, 1971).

The essence of these definitions seems to be that computer simulation attempts to mimic or to represent some aspect of real life and that the simulation process is embodied in the form of a high speed digital computer program.

A behavioral simulation model attempts to represent logically and mathematically some category, type, or class of human behavior. The class of human behavior of concern in behavioral models is the psychological response, and to some extent, the physiological response. The behavioral model is concerned with person-machine, person-person, and person-environment relationships and with their interactions, i.e., with the performance of individuals and groups under varying conditions due to the environment, training, operational doctrine, characteristics of equipment systems, and individual capabilities.

Mere representation is not a sufficient goal in itself for a behavioral model. To be useful for more than descriptive purposes, the representation should be of such a nature that it allows manipulation of extrinsic (situational/environmental/equipment) or intrinsic (individual and group) variables so as to allow determination of the effects of the manipulation on some output measure or on some other variable which exerts an affect on the output.

Hence, we define a behavioral computer simulation model as a representation of behavior and behavioral influences implementated on a digital computer so as to allow control or prediction of an event, or event sets. This definition emphasizes both the structural and the utility aspects of a behavioral simulation model.

Models versus Theories

While a model will often be based on theory, a model of human behavior or of some aspect of behavior is not, per se, a theory of behavior. The two should not be confused. Table 1-1 compares and contrasts models and theories. A model possesses a different purpose than a theory:

- Feigl (1949) proposed that the purpose of a theory is to state functional relationships. While a model may include functional relationships within its structure, the goal of simulation modeling, as stated above, is to allow for prediction or control of the effects of manipulating extrinsic or intrinsic variables on an output measure.

- Chapanis (1961), holds that models are to be judged on the basis of utility while the test of a theory rests on validity. The "utility" of a model, to us, means the extent to which the output assists the decision maker in reaching a decision.

- Because they are fundamentally representational in nature, models are descriptive in content. Because the goal of theories is to state functional relationships, as a minimum, they must rely on some type of correlational content.

- Theories may postulate unknown or intervening variables of unknown or partially known dimensions. In contrast, each variable in a simulation model must be defined, be scalable, and its relationship to other variables clearly specified.

- Whereas models are highly quantified so that specific representations can be constructed with precision, in theories quantification is not essential.

Table 1-1

Comparison of Models and Theories

	Behavioral Model	Theory
Purpose	Predict or control behavioral implications--"What happens if"	Describe functional relationships--"How it works"
Criteria of Acceptance	Utility or assistance in decision making	Validity
Content	Descriptive	Correlational
Variables	Measurable/scalable	May be hypothetical
Quantification	High	Optional
Generality	From full to limited	Full

A behavioral model may be highly specific or general for a class of behavior. Theories attempt to cover as general a sphere of interest as possible.

Utility of Behavioral Models to the Army

Models in general and behavioral models in particular can help the Army weapon system and the personnel subsystem developers to answer a variety of questions which can not be easily answered through other methods. The upper part of Figure 1-1, which was originally suggested by Haythorne(1963), places simulation models into perspective relative to the fidelity of various available evaluative/predictive techniques. As one proceeds along the time continuum, the techniques approach reality to a greater extent. Hence, the fidelity of computer simulation falls between deterministic analysis and physical simulation. The lower portion of Figure 1-1 portrays the DoD system development cycle from the basic research phase through exploratory development to full scale production and operational deployment. Different evaluative/predictive techniques assume appropriateness during various stages in the equipment system development cycle. Qualitative estimates of system effectiveness are viewed as sufficient during the basic research phase of system development. As the system design matures and hardens in the exploratory development and the advanced development stages, deterministic and computer simulation evaluative techniques play a dominant role. In the more advanced stages of the development, physical simulation and various field operational and technical evaluations play a more important role.

In this context, behaviorally oriented computer simulation is in a position to provide the system developer with answers to a wide variety of questions, while a system is early in the development phase. Questions can be answered such as:

- What are the quantitative personnel requirements?
- What are the qualitative personnel requirements? Where, during system utilization, are operators most overloaded? Underloaded?
- How will cross training improve system effectiveness?
- Are the system operators able to complete all of their required tasks within the time allotted?
- Where in the task sequence are operators/groups likely to fail most often? Least often?

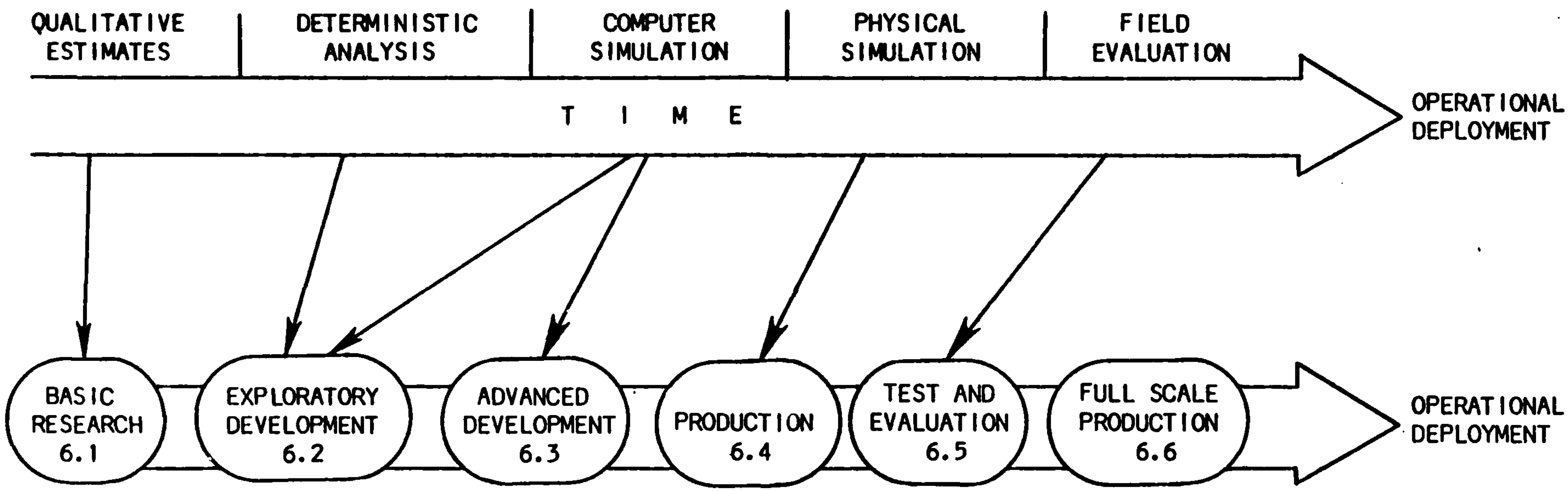

FIGURE 1-1. RELATIONSHIP BETWEEN VARIOUS SYSTEM EVALUATIVE TECHNIQUES AND DoD SYSTEM DEVELOPMENT CONTINUUM.

- In which state(s) of the system is the "human" subsystem (and/or components thereof) least reliable and why?
- How will task restructuring or task realloca-tion affect system effectiveness?
- How much will performance degrade when the system operators are fatigued? Stressed?
- How will various environmental factors (e.g., heat, light, terrain) affect total man-machine system performance?
- To what extent will system effectiveness improve or degrade if more or less proficient operators are assigned?
- How do group factors such as morale and cohesion affect system performance?

Computer simulation provides the quantitative data so that analysts can develop answers to such questions while systems are in the exploratory as well as the advanced development stages. The answers to such questions can then be used for Army system redesign or modification early in the developmental cycle. Once the design changes have been decided on, a series of computer simulations can be completed representing the modified system to predict the extent of the improvement to be brought about by the modified system.

A corollary to and extension of the uses of computer simulation discussed above is the employment of computer simulation to compare the effectiveness of alternate system concepts. Here, two or more Army system concepts are modeled with the end result in mind of selecting the "best" concept for further development.

In the general case, possibly the greatest advantage of models to the Army lies in their ability to provide the basis for system oriented tradeoffs during the early stages of a system's development. Figure 1-2 presents a hypothetical representation of the gain in system effectiveness (as estimated by computer simulation) when various amounts of money are invested either in physical design improvement or system operator/maintainer training improvement. In the illustrative example, if less than about 300 cost units are available, the system manager would be well advised to invest most, if not all, of his available funds in training rather than physical redesign. In the 450 cost unit area, physical design improvement produces an increase in system effectiveness that equals the gain to be anticipated from increased training emphasis.

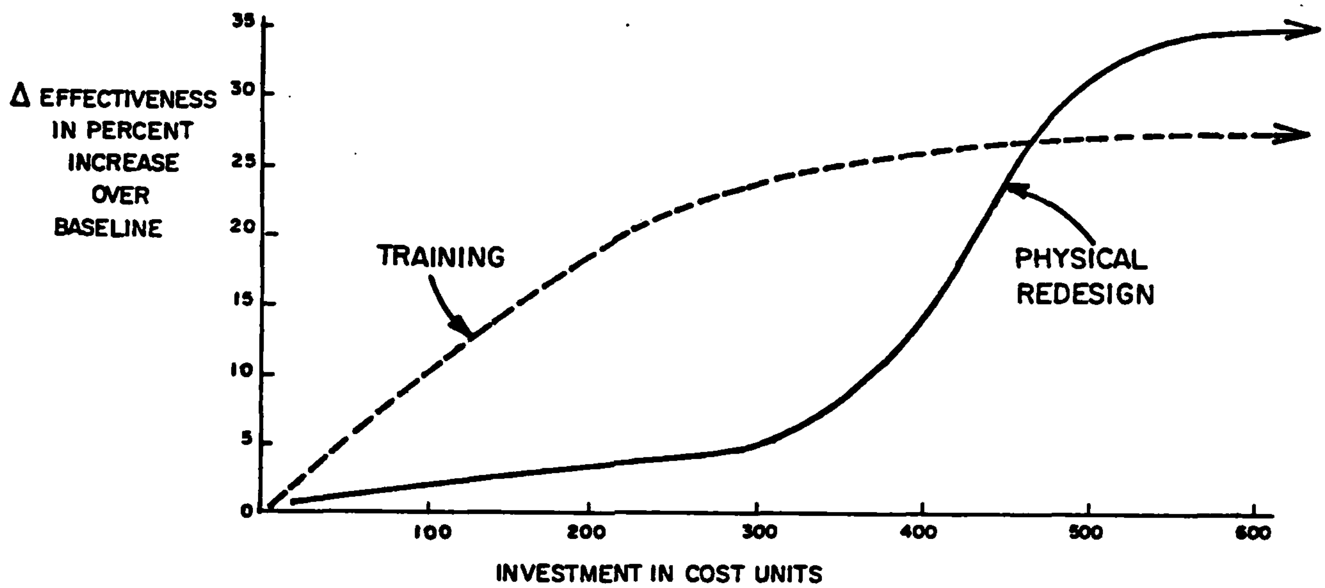

Figure 1-2. Hypothetical example of tradeoff between training and physical equipment redesign as indicated by simulation results.

When more than 450 costs units are available for improvement, these data show the best investment to be in a physical redesign. Note that the asymptotic situation is achieved for both alternatives in the range of 500-600 cost units. Exemplary of the type of decision-enabling situation which is produced by simulation is the not-so-obvious results generated from the Figure 1-2 data which are shown in Table 1-2. For each level of funding available for system improvement, Table 1-2 shows the way to greatest payoff:

0-300 cost units - buy training
450 cost units - buy training or physical redesign
500 cost units - buy physical redesign.

Table 1-2 also shows that no advantage can be gained by applying more than 1200 cost units and that the largest payoff in terms of Δ effectiveness per unit funding applied, is in the 200 cost unit range (see * Table 1-2).

Table 1-2

Values of Δ Effectiveness Resulting from the Best Choices of Funds Application for Given Amounts of Funds Availability

If this number of cost units were the available funding for improvements	and these funds were divided among: Physical Redesign	Training	the resulting Δ effectiveness would be:	The ratio Δ effectiveness/ cost unit is then:
100	0	100	8	.080
200	0	200	18	*.090
300	0	300	23	.077
400	0	400	26	.065
450	0	450	27	.060
450	450	0	27	.060
500	500	0	32	.064
600	500	100	40	.067
700	500	200	50	.071
800	500	300	55	.069
900	500	400	58	.064
900	600	300	58	.064
1000	600	400	61	.061
1100	600	500	62	.062
1200	600	600	63	.063

Purpose of Behavioral Simulation Models

The major purpose of simulation models in the military situation is to help decision makers to make decisions. In this role, simulation models provide a quantitative information data base for decision making that is usually not available from other sources. From this, it follows that the ultimate test of the utility of a computer simulation model is the extent to which it provides unique information or information at a quality level that is not available from other sources.

If the decision involves the system personnel or the interaction of the personnel with the equipment, a behavioral simulation model is required. A model of the physical system is inadequate for such purposes if the human performance element is missing from the simulation. Accordingly, the behavioral simulation model will provide personnel subsystem oriented information (e.g., effects of varying manning, skill level, training, time stress, situational stress, leadership style, motivation on system performance) which forms a partial basis for decision making.

Model Validity

Note that the model utility premise ignores questions of model validity. The validity issue is believed to be an important (even critical), but secondary, issue in simulation model development and application. While some validity represents a necessary ingredient in any model, it is quite possible to have a highly valid model which yields little useful information for decision making purposes. Conversely, a model of moderate validity may provide the only available data thus allowing the decision making process to proceed on an empirical basis rather than on the basis of intuition alone.

Scope of the Present Report

The present report's subsequent chapters attempt to set behavioral simulation into focus. To this end, Chapter II presents various behavioral models. The chapter attempts to show the diversity of the field, the current state-of-the-art, and how current Army system models might benefit from the inclusion of behavioral models. Chapter III discusses a number of pervasive issues in behavioral modeling through computer simulation. Chapter IV assesses the current status of behavioral models and projects future trends in the field.

II. CURRENT BEHAVIORAL MODELS

There is now on hand a considerable body of experience with simulation models. Such models have been developed both within the Army and elsewhere to simulate a variety of behavioral effects on system performance.

Examples of Behavioral Models

Early Models

The first integrated attempt at behavioral modeling on the basis of high speed computer applications is believed to be that of Siegel and Wolf (1969). This work evolved from a requirement for a method for evaluating the work load placed on operators in person-equipment systems. Siegel and Wolf constructed an event sequenced simulation in which the individual action elements (subtasks) of a task performed by either one or two operators are successively simulated. To introduce the variability inherent in individual behavior, Siegel and Wolf specified that each individual response time to complete a subtask be selected stochastically. They also simulated through probabilistic methods the branching, looping, waiting, and subtask repetition inherent in the performance of any task. A major feature of this early model was simulation of the reactions of the operators to time stress. This feature modifies the simulated operators response time and success probability as a function of the time remaining to complete a task and an individual operator stress tolerance input parameter value.

As the behavioral modeling art progressed and confidence in its power increased, more variables and variables of increased complexity have been included in such simulations. For example, one Army Research Institute battle simulation model (Siegel, Wolf, Ozkaptan, & Schorn, 1980) includes the effects on performance of "physical" variables such as light level, terrain advantage, and enemy/friendly personnel strength ratio. Other recent models have included simulation of the effects of such psychological variables as group cohesiveness, group morale, leadership expectation, and learning. The NETMAN model of the Army Research Institute for the Behavioral and Social Sciences includes level of aspiration and a decision making psychological variable. Table 2-1 lists some of the behavioral simulation models which have been reported in the literature.

Table 2-1

Examples of Behavioral Simulation Variables, Their Source, and Purposes

MODEL	AUTHOR(S) and DATE	PURPOSE	CONTENT	VALIDATION	COMMENTS
1. Cognitive process of foreign policy decision-making	Bonham, G. M., Shapiro, M. J., & Nozicka, G. J. (1976)	To investigate policy problems, e.g., people's mistaken views and irrational choices; to understand the cognitive processes and to predict actions of policy makers.	Decision maker's belief system is represented by a map of causal linkages between four processes: policy objectives, beliefs about international events, policy recommendation options, values (e.g., national security) which they try to satisfy.	Applied to Yom Kippur War, but model's predictions were not validated.	Mathematical base is digraph theory. Digraphs of decision maker's belief systems are computer converted to adjacency matrices, from which reachability matrices are computed. Implemented in FORTRAN IVH and can process up to 200 concepts.
2. Sociometric map of attractions and repulsions	Levin, M. (1976)	The model is instructional and analytical, presenting sociometric data in graphic form.	Conversational format: aquestion is asked, the user responds, the program either asks another question, gives an answer, or an instruction. Sociograms are displayed on the screen. Dyadic and triadic choices can be represented in output.	None	The program provides a quick, easy means of viewing empirical sociograms, as well as the frequency with which triads occur. Determination of cliques is possible through distance measurements. The program can be used to study the impact of new members on a group.
3. Travel simulation model for outdoor recreational areas	Lucas, R. C., & Schechter, M. (1977)	To formulate and evaluate management policies based on visitor patterns at recreational sites.	Visitor movements and interactions are entered at various dates, clock times access points, routes of travel, overtaking slower moving groups, passing groups going in the opposite direction, passing groups camped out, group size, method of travel, travel speed.	Tested in two wilderness areas. Encounter and pattern validities were good when matched against actual data.	The model allows comparison of alternatives toward criteria of public benefit, e.g., use of key areas, congestion, solitude, number of visitors entering at different places and times. The model is coded in GPSS, Version V.
4. Parameters of retention ability in presidential elections	Wanat, J. (1976)	To determine the ability of each party, in a two party system, to keep voters from one election to the next and to attract new voters.	Proportion of voters shifting party vote from one election to the next, proportion of voters who drop out after an election, party split, number of new voters.	None	A stochastic model with varying assumptions about turnout, vote split, and party retention ability.
5. PARADIGM--a simulation of competing ideas	Rubin, H. J. (1978)	To measure how message characteristics influence the speed with which one idea overtakes another idea in popularity.	Five types of interacting individuals are modeled--advocates of two ideas persuading others to adopt their beliefs, advocates of two ideas unable to persuade others, and a neutral who does not believe in either of the ideas.	None	A representation of social communication that provides data on the speed of diffusion of a message, the penetration, and the influence of the spread.
6. Student performance	Roberts, N. (1974)	To illustrate effects of several variables on student performance.	Student potential, student's aspirations, teacher expectations, time for enlarging student's knowledge, time teacher had available, student's performance, time for changing teacher's expectations, teacher's objectives, time for changing student's goals.	None	Three elements are most crucial: student goals, teacher expectations, and the amount of extra help given. The effects of these variables are generated by the model.

Table 2-1 (cont.)

MODEL	AUTHOR(S) and DATE	PURPOSE	CONTENT	VALIDATION	COMMENTS
7. PROF--Information processing policies	DiSalvo, V., & Bochner, A. P. (1973)	To examine individual differences on information processing.	Simulated trait profiles are rated; ratings are input to model. Calculates validity coefficients, Q-type factor analysis, then captures raters' policies.	None	The technique identifies raters with similar policies. It defines the captured policies of raters through the relative importance assigned to each profile.
8. Urban decision making via the CITY MODEL	Olson, S.H., Berlin, G.N., & Gulland, L.S. (1973)	To explore the decision making process in urban political economies.	The decisions involved relate to contracts, transactions, wage and price setting, capital investment, budgets, personal and household time budget	None	Model input is transactions. It balances accounts, calculates interest and depreciation, assigns workers to jobs, simulates in-and-out-migrations of people, and introduces national business cycle variations.
9. Family planning	Vertinsky, I., Buckingham, S.L., Walters, C.J. & Zaltman, G. (1972)	To model family planning activities and population growth.	Distance to medical facilities, cost of health services, utilization of health services, knowledge of birth control technique, cost of technique, discomfort of usage, side effects, religious norms inhibiting its use, and feedback (success with its use).	Partial-high correspondence between simulated data and official publications, no validation on the demographic sub-model.	The model provides a national perspective of family planning in the context of changing social and demographic environments; provides an evaluation of program success, permits forecasts of demands for contraceptive techniques, evaluates effective mixes of techniques.
10. A computer game player	Reisman, S. (1972)	To simulate the cognitive processes of humans playing dominoes.	The program uses inferential or noninferential strategies.	Validity was demonstrated by comparing the simulation with empirical protocols.	The program acts as a player and monitor, e.g., distributes tiles, checks whether legal tiles were played, and tallies the tiles.
11. Political interest model	Kornberg, A., Mishler, W. Smith, J., & Naylor, T.H. (1972)	To model the process of developing political interest among young political party leaders, and how to stimulate greater levels of political interest through social processes.	Effect of: peer group, school environment, family, public figures, public events, upward change in political interest.	Validated through inspection of theoretical propositions, test of significance, tests of predictive accuracy.	The model accounts for three age intervals: 14-18, 18-22, and 22-26. All variables coded: 1 when a change in interest was reported and when a variable was influential, and 0 for absent effects.

Table 2-1 (cont.)

MODEL	AUTHOR(S) and DATE	PURPOSE	CONTENT	VALIDATION	COMMENTS
12. DICE--a model of jury decision making	Penrod, S., & Hastie, R. (1979)	To determine the probability that a randomly selected jury will vote to convict, and will produce a conviction, an acquittal, or a hang. Also, to determine the verdict probabilities for a first ballot.	Six major parameters are: jury size, decision rule (e.g., majority, unanimity), binomial probability of guilty votes, transition probability function (the persuasion/deliberation process), individual differences (persuasion resistance), and maximum number of ballots.	Compared results produced by juries and those obtained from DICE simulations. The distribution of verdicts matched well, as did the rate of vote changing.	Provides data on all six parameters plus deliberation times. Insights into the deliberation process are provided through the relationship between group size and persuasion and through the assessment of the impact of individual differences on the persuasion process.
13. Ingestion control model	David, J.D., & Levine, M.W. (1977)	To develop a model to describe feeding behavior.	The input variables are strength of flavor, evaluation of flavor.	Predictions were supported by laboratory studies with rats.	Predicts ingestion rate and total consumption. Ingestion rate equals the product of flavor strength and its evaluation. The model converts rate of ingestion to amount (volume equals the time integral of rate of inflow) and provides data on rate changes over time after initial contact with food. The quantity of food expected to be consumed is also provided. The model has not been computerized.
14. Process-Tracing model of judgment	Einhorn, H.J., & Kleinmuntz, D.N. (1979)	To model an individual's cognitive rules based on his verbal protocols and formalizing them in a computer algorithm.	The cues attended to in collecting information, individual's strategy for combining information.	Moderate predictive accuracy was obtained in a study involving adjustment classifications of MMPIs.	Predictions are made for complex judgments. The model considers the order in which data is collected.
15. Arousal model of intimacy	Patterson, M.L. (1976)	To explain and predict in the expression of interpersonal intimacy behaviors of Person B following a set of behaviors by Person A.	Standing features such as distance, body orientation, posture; dynamic features such as eye contact, facial expression, verbal intimacy, and touching.	None	Predicts arousal changes of a positive or negative emotional state. Positive emotions are liking, love, relief. Negative emotions are anxiety, discomfort, and embarrassment. The model has not been computerized.
16. CAMAS--(Computer-Assisted Manpower Analysis System)	Niehaus, R.J., & Sholtz, D. (1974)	The use of computer simulation model to determine the numbers and types of employees to be hired and fired at various points in time.	Inputs are: the number of employees on board for a particular period by occupational specialty and level, the number of hires, fires, and retirements by period, the goal or number desired, and transition rates (movements from one job to another).	None	The model calculates the rates of movement of the work force and determines future population by job-type, personnel requirements for the future, and turnover rates. The determinations can be made for individual activities, geographic area or any type of subdivision. It can also be determined for population subsets such as sex, age, length of service, and minority membership.

Table 2-1 (cont.)

MODEL	AUTHOR(S) and DATE	PURPOSE	CONTENT	VALIDATION	COMMENTS
17. Vector model of individual differences	Inukai, Y., Saito, S., & Mishima, I. (1980)	To examine a spatial representation of judged surface roughness of metal surfaces and the factors producing individual differences in an analytic model.	Roughness of metal surfaces was varied.	Results compared favorably with previous work which employed another method.	The model was not computerized.
18. Sequential Scan Model	Carter, R.C., & Cahill, M.C. (1979)	To use a computer model to describe search time data of color coded targets of varying densities.	The variables are: density, code size, and number of items per category, number of colors used to code stimuli.	The computer model accounted for 84% of the variance.	Search times were predicted by the model.
19. Human operator model for road driving	Baxter, J., & Harrison, J.Y. (1979)	Describe a driver's behavior through a nonlinear mathematical model.	Vehicle lateral position, vehicle heading angle, preview distance, vehicle speed on a CRT driving simulator.	Validated against experimentally obtained data.	An optimization procedure is used to evaluate model parameters; driver's action is best represented "by a pure time delay cascaded with a classical hysteresis nonlinearity."
20. Statistical quality control model	Drury, C.G. (1978)	To predict the probability of accepting a good item and the probability of rejecting a faulty item.	Sample size, flaws in samples, search times, probabilities of acceptance.	None	Produces operating characteristic curves (the probability of accepting a batch as a function of the incoming defective fraction), acceptance and rejection rates, mean search time.
21. Organized Crime Analysis Program (OCAP)	Harris, D.H. (1978)	To analyze organized criminal operations, to determine necessary analytical information, and to reduce the time and effort to complete analytical routines.	1. Individuals, organizations, places, telephone numbers, and criminal records that could be linked to one another; 2. relationships that link one entity to another; 3. an estimate of the strength of the link between two entities; 4. an estimate that the link actually exists.	No estimates for time savings. However, analysts using OCAP claimed that the program provided them with more precise information than they had previously.	A listing is provided of direct links and associated strengths between each entity and every other entity; indirect links and their strengths are calculated; link networks are provided; and link paths connecting any two entities.
22. Optimum control model in display analyses	Baron, S., & Levison, W.H. (1977)	To solve the information processing aspects in display related problems for symbolic and pictorial displays.	The display elements are: rate of change of the quantity displayed, the operator's time delay, noise, estimation (tracking) errors, eye to display distance, and attention sharing.	Validated in on analysis using a Terminal Configured Vehicle display.	Thresholds are developed for: eye to display distances in inches, and tracking error to noise. Display recommendations can be developed for different attentional workloads.
23. Internal model of helmsman	Veldhuyzen, W., & Stassen, H.G. (1977)	To utilize an internal model in a man-machine system.	For analyzing a helmsmen's behavior the input data included: ship's rate of turn, ship's inertia, the moment which can be exerted on the ship's hull by the rudder, the ship's stability, rudder velocity, time, yawing motions. The input for the helmsman include: the desired heading, the desired rudder call, the disturbed heading, undisturbed heading.	The empirically obtained values of performance were reasonably predicted. Heading error scores showed significant differences.	Predicts: future ship states, the helmsman's actions to control the ship, ability to keep a course, and the rate of turn.

Table 2-1 (cont.)

MODEL	AUTHOR(S) and DATE	PURPOSE	CONTENT	VALIDATION	COMMENTS
24. MPQ (Manpower Planning Quotas) Model	Ceriello, V.R. & Frantzreb, R. B. (1975)	The main objective of the model is to determine the level at which next year's recruiting and training quotas should be set.	Input data include: growth rate of staff, attrition rates, training program retention rates, transfers and promotions, targets for training program graduates.	None	The model indicates: (1) the number of people that will be required and from what sources they should be obtained, and (2) the training quotas required up to 14 years in the future. The model forecasts each of the content variables. Groups are considered rather than individuals.
25. HAS--Hostile Attack Simulation	Siegel, A.I., & Wolf, J.J. (1978)	To simulate personal, psychosocial, and group interactive aspects of defending nuclear facilities.	Proficiency/training of the defender, defender's stress threshold, probability of accurate message transmissions for accurate and inaccurate receptions, listener's accuracy of reception, probability of transmitting a message accurately, visibility level for defenders, distance between attack group and target area, time since exposure to nuclear radiation, radiation level, elapsed time from mission start through the current event.	No predictive validity. Construct validity is defensible since constructs were empirically derived.	The program provides: effects of radiation on information processing, psychomotor coordination; the effects of communication on information processing; stress values; cohesiveness; the effect of visual ease on psychomotor coordination; the effect of time on psychomotor coordination; the effect of fatigue on information processing; proficiencies of defending teams.
26. MAIN--simulation of human performance in electronic imagery systems	Siegel, A.I., Wolf, J.J., & Williams, A.R. (1978)	To simulate ground based processing of targets as viewed by operators of photo-reconnaissance data obtained by airborne side-looking radars.	Target images (with varying luminance changes at the border), target size, flashing and moving targets, target shape. Operator speed/proficiency, current stress value of operator, operator stress threshold, probability of generating a primitive without change, dif-different prototype images, target visibility, type of target, number of target types, similarity of target appearance, node to node movement probability, goal importance, entry node probabilities, number of decision steps, identification of the operator involved, message length, mean sentence length, standard deviation of sentence length.	None	The programs determine: operator time required for task performance and adequacy of operators' task performance for five different modules: scan/detect, classification, alternate classification, decision, and communication.
27. NETMAN--simulation of message processing in military exercise control and evaluation systems	Siegel, A.I., Leahy, W.R., & Wolf, J.J. (1977)	To simulate information processing by Army personnel in field exercises and to test the effectiveness of a system composed of up to three net-	Input parameters are operator stress, aspiration and performance, fatigue, execution time, and success/failure.	None	The program calculates information loss and an effectiveness index composed of thoroughness, completeness, and responsiveness measures.

Table 2-1 (cont.)

MODEL	AUTHOR(S) and DATE	PURPOSE	CONTENT	VALIDATION	COMMENTS
28. Intermediate size crew model--P420	Siegel, A.I., Wolf, J.J., & Cozentino, J. (1971)	To simulate man-machine systems operated by crews of from 4 to 20 members.	Scheduled event data include such inputs as: duration, essentiality, crew size, energy consumption, etc. Input data examples for equipment and repair events are: failure rate, repair time, mental load. Examples of input data for emergency events are: probability of occurrence, recovery time, and expenditure rate of consumables. Personnel input data examples are: percentage of fully qualified crew members, cross training probability, average stress threshold, sleep rate per day, and daily caloric intake.	An operational Vietnam river patrol mission was simulated and validated by comparing the simulation results with those obtained from interviews conducted with Coast Guard officers.	In addition to providing output data for the various input parameters, the program provides crew pace data showing the effect of speed of personnel on the number of successful events completed; data can show the effect of stress on successful and failed events, the effect of crew qualification on mission results, the effects of a low supply of expendables (e.g., water and fuel) on mission results, the length of the workday on the hours worked, and the effect of varying crew size on system performance.
29. One- and two-man/ machine model	Siegel, A.I., & Wolf, J.J. (1969)	To determine: if an operator can successfully complete the tasks within a given time limit, the success probability for slower and faster operators and shorter and longer time periods, the effect of stress on performance, and the distribution of failures as a function of operator stress tolerance and operator speed.	Input data include: type of subtask, subtask essentiality, idle time between tasks, sequence of subtask performance, subtask execution time, subtask probability of success, time remaining to perform subtasks, goal aspiration, stress condition of operator, team cohesiveness.	Validation studies were accomplished for both the one-man and two-man simulation for several different types of mission (carrier landing, missile launching, in-flight refueling). All results for the model's prediction ability were favorable.	The following data are provided for each operator: stress threshold, time used, time available, time overruns, stress, cohesiveness and goal aspiration at the end of the iteration. The model produces graphic plots such as the probability of success as a function of speed, time available, and stress threshold.
30. Group simulation of man-machine systems	Siegel, A.I., & Wolf, J.J. (1969)	To predict qualities of larger (up to several dozen men) man-machine systems such as: system efficiency, crew morale and cohesiveness, time devoted to equipment repairs, manpower time shortage as a function of crew size, proficiency of crew members, and man-hour loadings and overtime.	Input data include: average time to complete action units, communications between stations to complete an action unit, importance of action unit, type of action unit (normal, training, difficult), equipment failure rate, average repair time, number of personnel required to operate equipment, probability of a crew member having one alternate and two alternate specialties, number of personnel types allotted to line and staff, crew size increments, morale threshold, working hours per day, probability of an emergency, proficiency for the average crew member, and crew member pay level.	Content and construct validity were tested through the simulation of typical missions and the model's results were compared with actual mission data. Favorable results were found.	Minimum crew size is determined from workload data; execution time from group member proficiency, morale, overtime load, number of men required, and average time. The model determines crew morale and cohesiveness, work groups, communications efficiency, proficiency of performance, action unit execution time, psychological efficiency, environmental efficiency, total efficiency, performance adequacy.

Table 2-1 (cont.)

MODEL	AUTHOR(S) and DATE	PURPOSE	CONTENT	VALIDATION	COMMENTS
31. SHIP II model	Schwartz, M. (1971)	To investigate alternative manning concepts, maintenance and work policies, training concepts, and equipment design characteristics for planned and existing ships in the fleet.	Input variables include: training session duration, hours/week/man, failure detection times, MTBF, probability of degradation, deferrals for assistants and parts, time in function, error probability, and manhours/day.	None	The model outputs are in four categories: manpower data, equipment information, task data, and ships readiness.
32. Maintenance manpower planning model	Burling, J. (1971)	To assist in making decisions about manpower requirements and to improve efficiency through different crew allocations and training schedules.	The input data are: number of people available for service by department, shift and day; manufacturing schedules, MTBF, MTD, machines performing the same work content (group number, department location, department responsible, number of machines, skills required to service), work calendar, maintenance operating policies, and number of people per service call.	Outputs from the model were compared with the results of one month of operation and showed an overall difference of less than 2%, in terms of persons, per department, per shift. Forecasting showed a difference in total manpower of less than 1%.	The output shows maintenance serviceman utilization and manufacturing machines waiting for service. It indicates the number of servicemen needed for optimum service, and the impact on service if equipment characteristics change, items of equipment are added or deleted, manufacturing schedules change, or maintenance policies change.
33. ADSTAP--model for enlisted force utilization	Silverman, J. (1971)	To plan and control manpower in terms of requirements, problem areas, and to test alternative manpower plans and policies prior to their establishment.	Inputs are starting inventories and rates of change. Other parameters in the system are: mean and standard deviation of length of service distribution, grade progression, promotion opportunity, criticality rating, cost, utility, pay grade, petty officer grade ratio, and career ratio.	None	The model produces a projection of the enlisted force by size and composition, plans for career development, enlisted advancement, strength management, training input, and personnel policy evaluation.
34. A model of the human shoulder	Kramer, R.R. (1975)	To model a shooter of shoulder-fired weapons so that predictions of a weapon's performance can be made before it is built.	Inputs are mass density, distance of tube axis to shoulder, mass of tube, mass of shoulder, mass of projectile, force exerted by shoulder on tube, length of projectile, and recoil impulse.	None	The model calculates the reaction force and displacement of the shoulder when it is impacted by a semi-impulsive force. The model has not been computerized.
35. A model for evaluating the effects of carbon monoxide emissions	Steinberg, S. (1980)	To predict the amount of carboxyhemoglobin in the blood of a person based on its cumulative level prior to a period of exposure plus the amount of carbon monoxide respired during the exposure.	Inputs are: percentage of carboxyhemoglobin in crew member's blood at the beginning of a mission segment, cumulative percentage at the conclusion of a mission segment, average carbon monoxide exposure level, work stress level, rate of diffusion of carbon monoxide in the lungs as a function of work stress level, respiratory volume as a function of work stress	None	The model calculates the carboxyhemoglobin content for each crew member of a military fighting vehicle (e.g., tank, truck, aircraft) at any time during a mission. The amount of carbon monoxide respired is a function of the concentration level, time of exposure, and workload of exposed person. The calculated values can be compared with proposed limit values to determine the effects on the individuals.

The diversity of categories and techniques, together with even a cursory review of Table 2-1, indicates that a wide variety of models has been developed and reported. Perhaps the time has arrived to focus on the development of fewer high quality models as opposed to a proliferation of models of unknown quality.

Combat versus Behavioral Models

When one is concerned with modeling in the Army context, it becomes important to distinguish between "combat" models and "behavioral" models. To our way of thinking, combat models simulate the physical aspects of a combat situation. They might include, for example, variables such as the type of weapons available to each opposing force, the terrain, the readiness condition of the equipment, the predicted mean time between equipment failures, availability of reserve forces, and the like. As such, combat models come to grips with many of the variables which exert a considerable effect on combat outcome.

Behavioral or psychological models, on the other hand, simulate or at least consider the effects of internal and environmental variables on the performance of the persons who operate and maintain the weapon systems and who implement the battle plan. Accordingly, behavioral models or behavioral modules can serve to affect the output of combat models as a function of the human element in the person-equipment system. Total system performance is then considered to be a function of both the human and the equipment elements of the system. Thus, simulating total system performance requires an integration of behavioral and combat (physical) elements.

Specific Behavioral Traits Modeled and Their Logic

Some further concept of the extent and methods of behavioral modeling can be obtained through an understanding of the logic of some of the behavioral variables which have been modeled previously. Modeling, by definition, is a representation. Accordingly, there must be some understanding of the psychological or behavioral process to be represented by a model before the model may be developed. To this end, the behavioral modeling process usually starts with some sort of literature analysis to isolate the variables important to the process to be modeled. Often, the literature indicates more salient variables than the modelist wishes to include in his model. In this case, a choice must be made among the available variables. Table 2-2 lists a set of criteria, employed by the present authors, which must be more or less satisfied before including a variable within a model.

The following sections present examples of various behavioral simulations. The simulations were selected to provide some concept of the scope and thrust of current behavioral simulations. A cognitive (decision making), motivational (level of aspiration), operator characteristic (physical capacity), and a visual recognition (perceptual) simulation are presented. Each of these was drawn from and constituted a part of a total or larger simulation.

Decision Simulation--Cognitive Example

A decision module was developed (Siegel, Wolf, & Williams, 1978) to simulate the operator's decision processes involved in an advanced electronic imagery system. The simulation logic follows from Simon and Newell's problem solving theory (Newell & Simon, 1972; Simon & Newell, 1971) but expands on that conceptualization by considering task complexity, decision utility, operator ability, stress, and Bayesian concepts. The Simon-Newell theory describes the problem solver as stepping, node-by-node, through the problem space until a solution (i.e., final decision) is reached. The node stepping represents the decision process where each step involves data collection, analysis, and evaluation and the problem space represents the size and structure of the decision task. The end result of the simulation is an indication of: (1) the correctness of the decision, and (2) the time required for the decision making.

The decision subroutine was based on decisions involving up to five decision alternatives (one and only one of which is correct) and six nodes (for a total of 11 states). The representation, as shown in Figure 2-1, may be viewed as a hexagonal structure which may be initially entered at any node. From any node, 11 choices are possible: stepping to one of the other five nodes, remaining at the node, or stepping to a solution state. Stepping to a solution state completes the stepping process.

Decision time, within the simulation, is calculated as a function of task complexity, stress on the operator, and number of steps to reach a solution. Decision correctness is determined by matching the solution reached (via the stepping process) to a given (input) correct solution. Within the step process, the step probability values, initially supplied as input, are affected by: (1) operator ability, (2) utility, and (3) a Bayesian process.

Table 2-2

List of Criteria Important for
Deciding Whether or Not to Include a Variable

AN ACCEPTABLE OR PREFERRED VARIABLE IS ONE . . .

(Data Availability) which is backed by substantial empirical data for the range of population to be modeled.

(Data Reliability) for which the error range of the available data is known and minimum.

(Relevance to Situation Being Modeled) which is critical to and possesses obvious saliency to the acts and behaviors of individuals and groups involved in the situation.

(Sensitivity) which will vary as the result of various events within a situation.

(Objectivity) which can be measured in the population under consideration.

(Amenability to Digital Simulation) which can be modeled without unwarranted assumptions and which will not require excessive processing time or memory requirements.

(Uniqueness) which is associated with unique output variance (each variable should contribute to the richness and completeness of the total model).

(Freedom from Need for Artifical Transformation) for which the ava. able data do not require excessive transformation, rescaling, preprocessing, or translation for digital modeling.

(Generality) which is applicable to a range of modeled situations.

(Comprehensibility) which is easily understood by the users of the model's output.

(Utility) which is most useful for answering the questions the planner and model's user wishes to ask.

(Event Oriented) which can be updated at the conclusion of each simulated event, and event indexed.

Table 2-2 (cont.)

(Susceptibility to Parametric Variation) which can be systematically varied over a range of levels or along a continuous scale.

(Freedom from Triviality) which will produce pronounced effects on input.

(Validity) for which the effects on performance (model output) and on other output and intervening variables are known, agreed on by most persons, and representative of the actual situation being modeled.

(Heuristic Value) which raises questions relative to the system being simulated as well as answer questions, provide explanations, analyze problems, provide solutions, and develop rules.

(Quantifiability) can be quantified, measured, and scaled.

(Supportability) is supported by a second body of literature.

(Realism) is apparent in the real life situation being modeled.

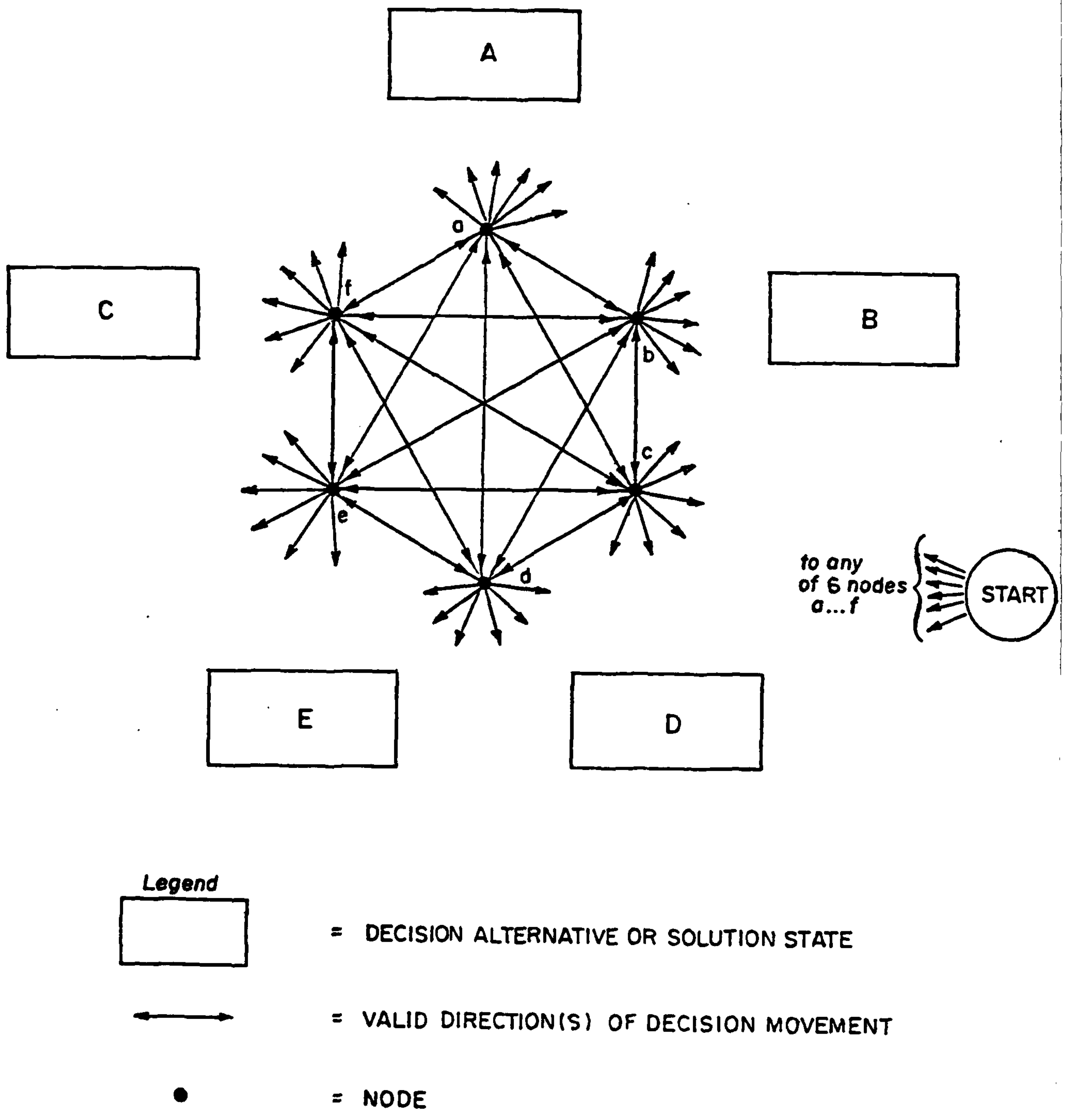

FIGURE 2-1. PARTIAL REPRESENTATION OF A FIVE-SOLUTION, SIX-NODE PROBLEM REPRESENTATION.

A top level flow chart of the simulation process is presented in Figure 2-2. After selecting the most proficient operator on the basis of his speed and proficiency, the step probabilities are first adjusted for operator ability and utility. Next (following resets), the decision implement step is taken. If a decision state is reached, the correctness of the decision is determined and the simulation proceeds to the decision time calculation sequence (boxes 9 through 12). If no decision state is entered, the input probability matrix is altered by a Bayesian process and a probability ratio, required in the later complexity calculation, is obtained. Then, performance of the next step is simulated, and the decision-no-decision check is again made. This process continues until a decision state is entered, or until the number of steps has reached the prespecified limit.

The operator ability adjustment causes an increase (higher proficiency operator) or decrease (lower proficiency operator) in the probability of a correct choice and in the time to reach a solution. The utility function is included because the best solution is not necessarily the solution with the highest probability. Utility is calculated on the basis of: (1) the importance of the decision on up to any three preselected mission goals, and (2) the effects of each course of action on the goals. The resultant utility values are used to adjust the input probability of moving toward each goal.

Monte Carlo processes are employed to complete the stepping process and the final decision is compared with the correct decision to determine decision correctness. If the completion of a step does not cause the simulated decision maker to enter a decision state, at the conclusion of the step the input probabilities are further altered on the bases of the Bayesian logic. This represents changes in the simulated decision maker's state on the basis of the information gained during the step.

To calculate decision time, three variables are considered stochastically: (1) the stress on the simulated operator, (2) the number of steps to reach a solution, and (3) problem complexity.

Level of Aspiration Simulation--Motivational Example

The decision module, described above, represents a simulation of a cognitive behavioral variable. The level of aspiration simulation described in this section, on the other hand, represents an example of the simulation of a motivational variable. The NETMAN model, a communication network simulation, of the Army Research Institute for the Behavioral and Social Sciences contains this subroutine.

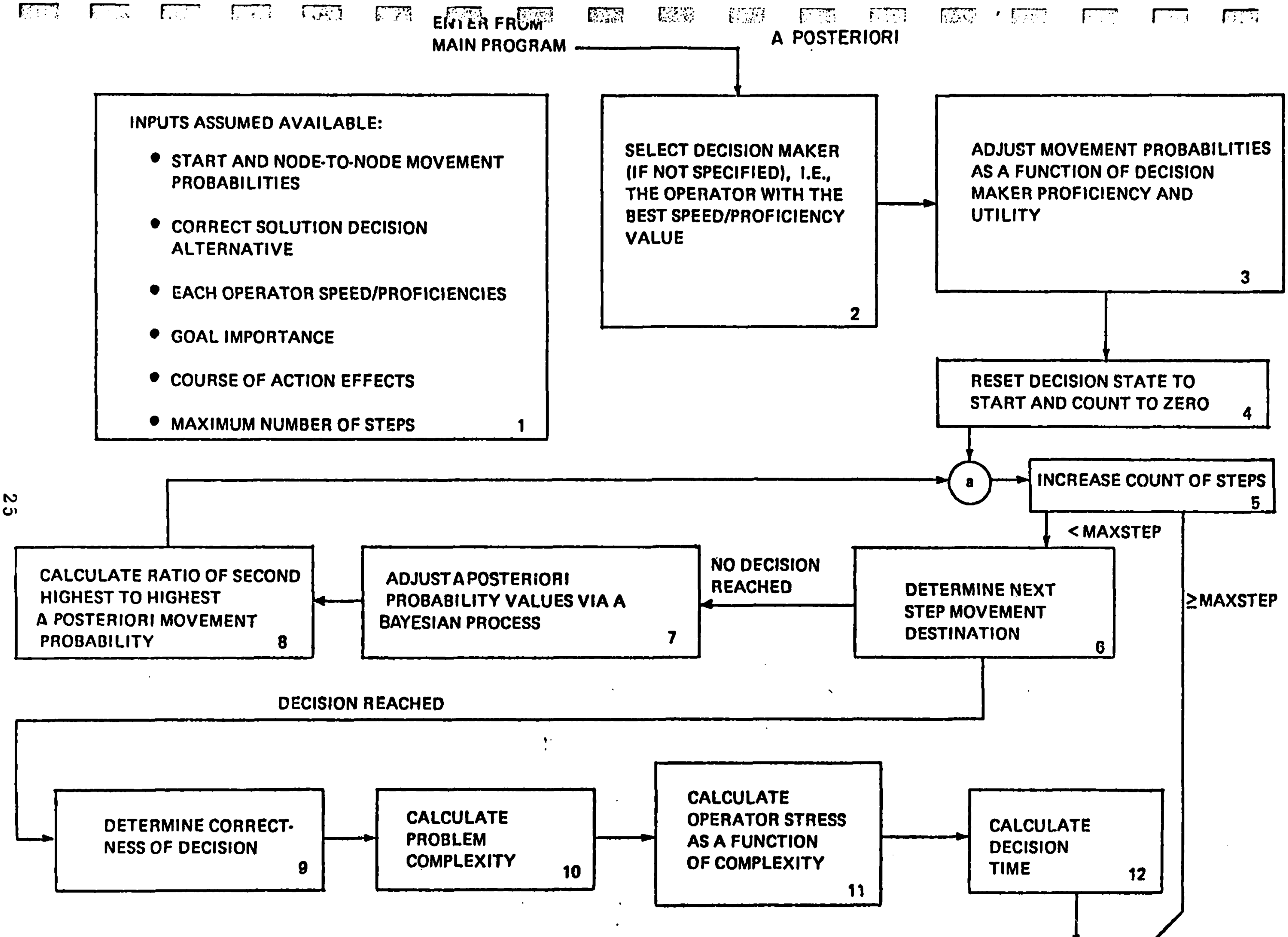

FIGURE 2-2. OVERALL FLOW LOGIC OF DECISION SUBROUTINE.

As described by Siegel, Leahy, and Wolf (1977), the simulation is based on the thinking of Lewin (1942) and of Kelly and Thibaut (1954). Accordingly, as for the decision simulation, the level of aspiration simulation is drawn from and based on behavioral theory.

The NETMAN model is an event sequenced simulator which concentrates on the message handling aspects of Army field exercise management systems. Aspiration level for each operator is based, within the model, on the success level each operator would hope to attain, where success record is defined as the ratio of the number of subtask successes to the number of subtask attempts. A simulated operator with an aspiration value of 1.00 would aspire to succeed in every one of his task attempts, while an operator with an aspiration value of 0.50 would have lower motivation and would be viewed as considering a rate of one successful attempt in two as acceptable.

The NETMAN model is fully dynamic and the level of aspiration of a simulated operator varies over the course of a simulation in accordance with his success record. This is accomplished by initially assigning individual aspiration values, as computer input parameters, permitting these values to affect the speed of operator performance, and then adjusting the aspiration values as a function of operator success record and the amount of stress incurred during the simulation.

Specifically, the simulation considers: (1) each operator's goal discrepancy--the difference between the aspired success record and the actual record, and (2) the difference between current stress on the operator and a stress threshold. (The stress threshold is also a value assigned as an input parameter.) Aside from the situation in which there is zero or near zero goal discrepancy, four discrete cases can exist:

Case 1	Positive goal discrepancy (i.e., aspiration in excess of actual performance recorded and stress below the threshold)
Case 2	Negative goal discrepancy and stress below the threshold
Case 3	Positive goal discrepancy and stress equal to or greater than the threshold
Case 4	Negative goal discrepancy and stress equal to or greater than the threshold

Case 1 presents a circumstance which possesses positive motivational value--the operator is not performing as well as he would like to, yet he is only mildly stressed, if at all. The psychological expectation is that he would strive to perform better, and the model effects this by generating a pace adjustment factor, which causes the simulated operator to work faster. Figure 2-3 shows this effect.

Case 2 further illustrates the dynamic aspect of level of aspiration, both as occurring in life and as simulated in the model. A negative goal discrepancy exists. This means that performance exceeds operator aspiration, and stress is still of only modest magnitude. Psychological theory (e.g., Deutsch, 1954) indicates that under these conditions, the operator would "raise his sights" and aspire to do more, since he demonstrated to himself that he has easily attained the initial level. In this regard, Krech and Crutchfield (1948) wrote:

> ...a successful individual typically sets his next goal somewhat, but not too much, above his last achievement. In this way he steadily raises his level of aspiration. Although in the long run he is guided by his ideal goal,..., nevertheless his real goal..is kept realistically close to his present position.

This process is simulated in the model according to a Monte Carlo procedure, in which aspiration is increased and the pace adjustment factor is set equal to 1.

Case 3 presents a circumstance of resignation. The operator is not performing as well as he would like, but is incurring stress equal to his threshold. Because of the stress, he has no choice but to accept his current performance level. The model effects this by reducing the aspiration value so that it equals the performance record. The simulated operator has ceased his upward striving and avoids the severe stress by accepting his current performance. However, associated with the cessation of upward striving, with the "edge" off the individual's motivation, one might expect to observe the beginnings of a partly voluntary and partly involuntary deterioration in performance. This effect is simulated in the model by modifying the performance adjustment factor so as to slow down the rate at which the operator performs his tasks (see Figure 2-3).

In Case 4, current stress is altered. Specifically, Case 4 presents the circumstances of performance exceeding operator aspiration, but stress being substantial. That is, the operator is incurring severe stress, despite the fact that he has attained the level of performance he set for himself. It seems reasonable that, as he reviews his success record, he stops "sweating it" quite so desperately for he has demonstrated that he can attain his aspiration level. In the model, this is simulated by reducing the operator's current stress to a value 18 percent below the stress threshold.

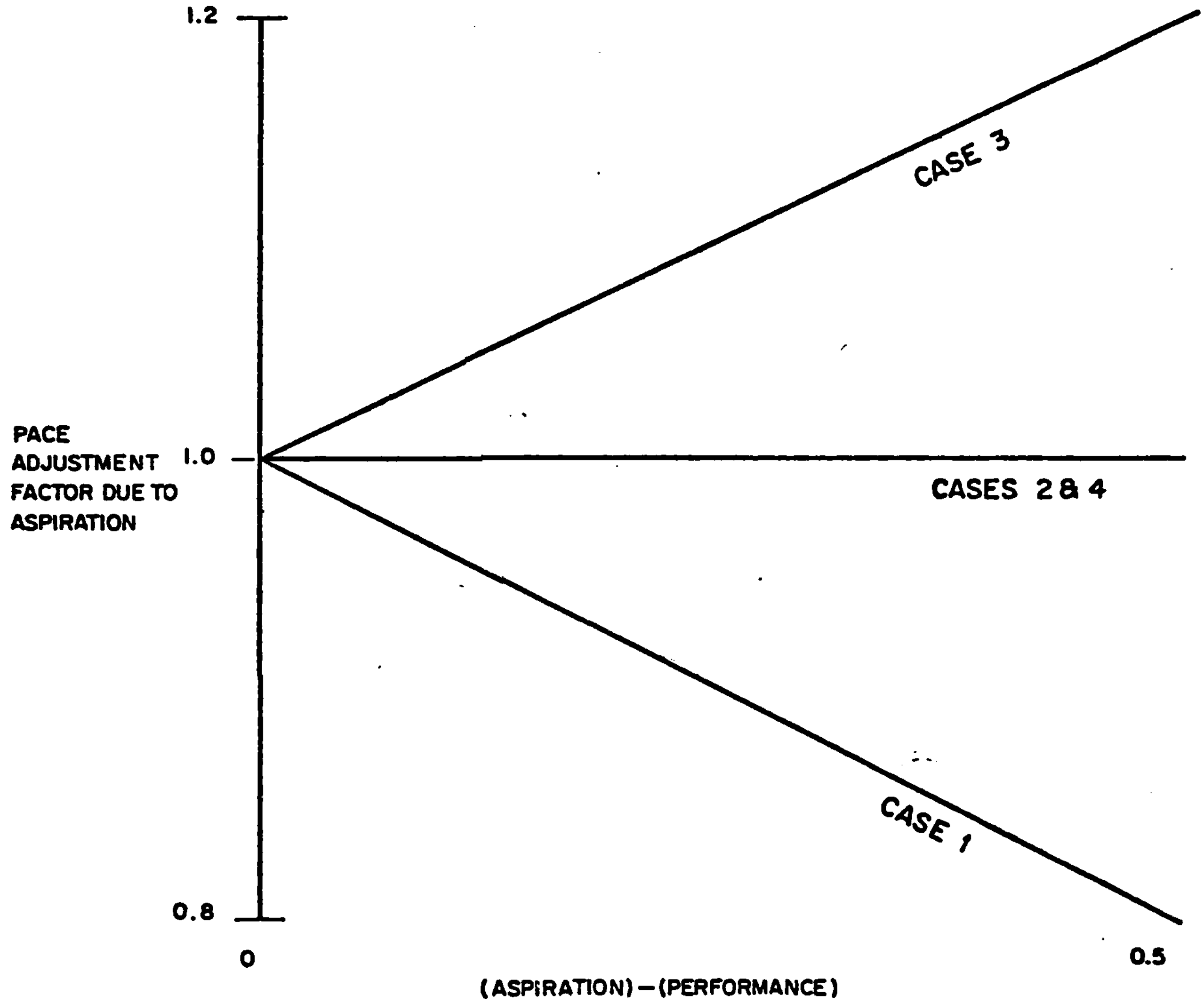

FIGURE 2-3. PACE ADJUSTMENT FACTOR, A FUNCTION OF ASPIRATION AND PERFORMANCE, AS REPRESENTED WITHIN NETMAN MODEL

Operator Characteristic Simulation--Physical Capacity Example

Another class of variables included in behavioral models includes the personal characteristics of the individual(s) simulated. Examples of such variables which have been included in prior models are operator speed, operator precision, and operator physical capacity (a strength measure).

The operator physical capacity simulation was selected to exemplify simulations in this class. Siegel, Wolf, and Cosentino (1971) developed a physical capability algorithm which is applied to each person in a work group at the start of the simulation of the performance of a subtask by the group. They drew their simulation approach from a literature analysis and assumed that the physical capability of a person decreases over time at work, total work completed, overexertion, and disability. They also assumed that physical capability varies among men. Siegel, Wolf, and Cosentino assumed the effects to be independent of each other and to act independently. The function for current physical capability of crew member M, PCC(M), was expressed analytically as:

$$PCC(M)=PC(M) \cdot PI(M) \cdot \left[1-(1-K1)\left(\frac{W}{CAL(M)}\right)^2\right] \cdot g\left(\frac{P_T}{P_N}\right) \cdot [1 - 0.1\ FAT(M)]$$

Here, PC(M) is the physical capability (related to strength) of the man, as calculated in another subroutine of the model (1 is an average value). PI (M) is the physical incapacity value related to minor sicknesses (also calculated in another subroutine). The factor $[1 - (1-K1)\left(\frac{W}{CAL(M)}\right)^2$ is termed the work factor. Here, W is the total work done (calories expended) on all events from the last sleep period up to and including half of the calories expected to be expended on the present event. In symbolic representation, W = ACAL(M), where ACAL(M) is maintained by the computer as the tally of accumulated calories expended. CAL(M) is the average number of calories expended in a normal working day for each man. The K1 term represents a disability factor--a fraction to which the work factor falls when a man has completed his normal quota of work during the day. Accordingly, within the simulation, a man's capability decreases as he continues to work and is reduced to the value K1 after a normal day's effort. The term $g(P_T/P_N$ represents an overexertion effect. Here, a mismatch of capabilities between the men assigned and the physical requirements of the events, in terms of energy (calories) required, are considered. The function is:

$$g\left(\frac{P_T}{P_N}\right) = \begin{cases} 1 & \text{when } P_T/P_N \leq 1 \\ \dfrac{c - P_T/P_N}{c-1} & \text{when } 1 \leq P_T/P_N \leq c \end{cases}$$

Thus, the overexertion factor has no influence as long as the work rate for the given event does not exceed the peak work rate expected for the men. Here, P_T = work rate for the event, P_N = peak work rate, and c = value of P_T/P_N yielding zero physical capability due to overexertion. The function is represented graphically as shown in Figure 2-4.

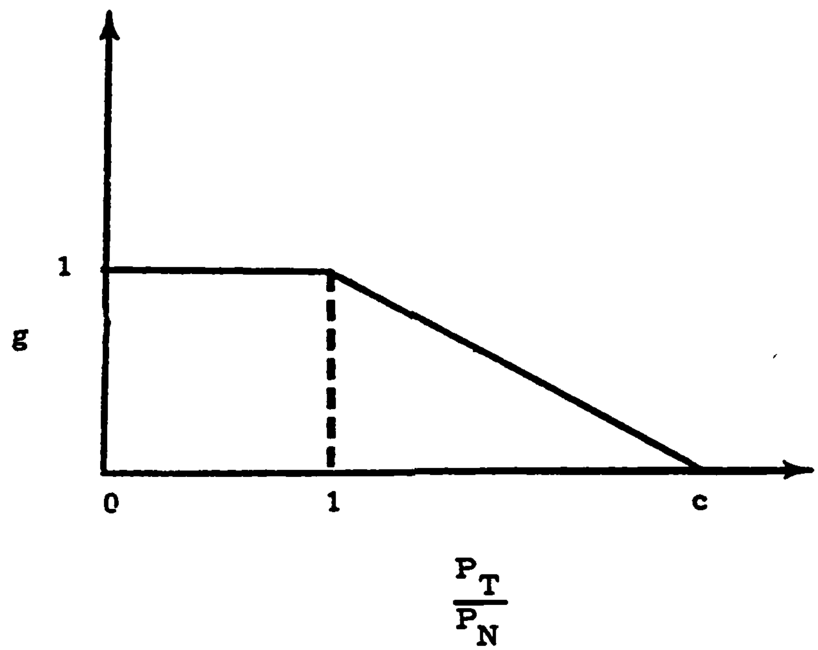

Figure 2-4. Overexertion function.

The last term of the PCC(M) equation is a function of the fatigue of the person(s) simulated--i.e., the time elapsed and sleep duration.

Visual Recognition Simulation--Perceptual Example

The final behavioral simulation to be described here involves recognition of objects by a person who views a cathode ray tube. Siegel, Wolf, and Williams (1978) developed this module to be embedded within a total simulation of the behavior of the system operator. The problem was to simulate the ability of an operator to correctly recognize (classify) an object once a discriminable pattern appears on the cathode ray tube.

Siegel et al. based the simulation on the "encoding specificity principle" Tulving and Thomson (1973). According to Tulving and Thomson, specific encoding operations are performed on what is perceived to determine what is stored, and what is stored determines what retrieval cues are effective in providing access to what is stored. The relative strength of cues as features constituting the perceptual context at the time of learning is thereby emphasized.

This thinking was mirrored by Reed (1973) who indicated the relative ascendancy of "features analysis" over "template matching" because features analysis rests on structuring the stimulus pattern in terms of primitive-characterized strokes to correspond to environmental invariants.

The recognition simulation of Siegel, Wolf, and Williams first calls for determining an initial classification probability on the basis of the number of strokes in the generated target. This first approximation is based on the logic of Deese (Zusne, 1970) that "stimulus complexity and ease of identification appear to be related as a U-shaped function." That is to say, features can neither be too few or too many and neither too similar nor too dissimilar to expedite the recognition of pictorial images. The function employed in the simulation (Figure 2-5) was developed on the basis of the data presented by Levine and Eldredge (1974) who asked experienced photointerpreters to classify a set of already detected targets.

This initial classification probability is then successively moderated (degraded) by four functions: (1) deviation from primitive in number of strokes, (2) deviation from primitive in angle of main stroke, (3) deviation from primitive in length of main stroke, and (4) deviation from primitive in curvature of main curved line, if any.

The first of these functions, deviation from the primitive in terms of number of strokes (Figure 2-6), is based on the conjecture that classification accuracy will degrade as the detail in a representation deviates from learned or anticipated detail. In a sense, a figure which is the same as a learned figure can be considered to be a structured stimulus. The influence of structure in form perception was acknowledged by Aiken and Brown, (1971) who asserted that "Thus it appears that the O, in dealing with relatively weakly structured stimulus configurations, will impose a consistent structure of his own generation, to organize the stimulus configuration" (p. 282). Arnoult (1960) concluded similarly. Empirical image evaluative studies (Coluccio & Wasielewski, 1970; MacLeod, 1964) in which the amount of structure (learned detail) was varied also support this conjecture.

The deviation from angle of main stroke function rests on the argument that a shape rotated out of the orientation in which it was learned is less readily recognized. As stated by Hake,

> Actually, the fact that recognition of forms and comparative judgments of forms deteriorates when forms are rotated with respect to the observer has been known for a long time (1966, p. 151).

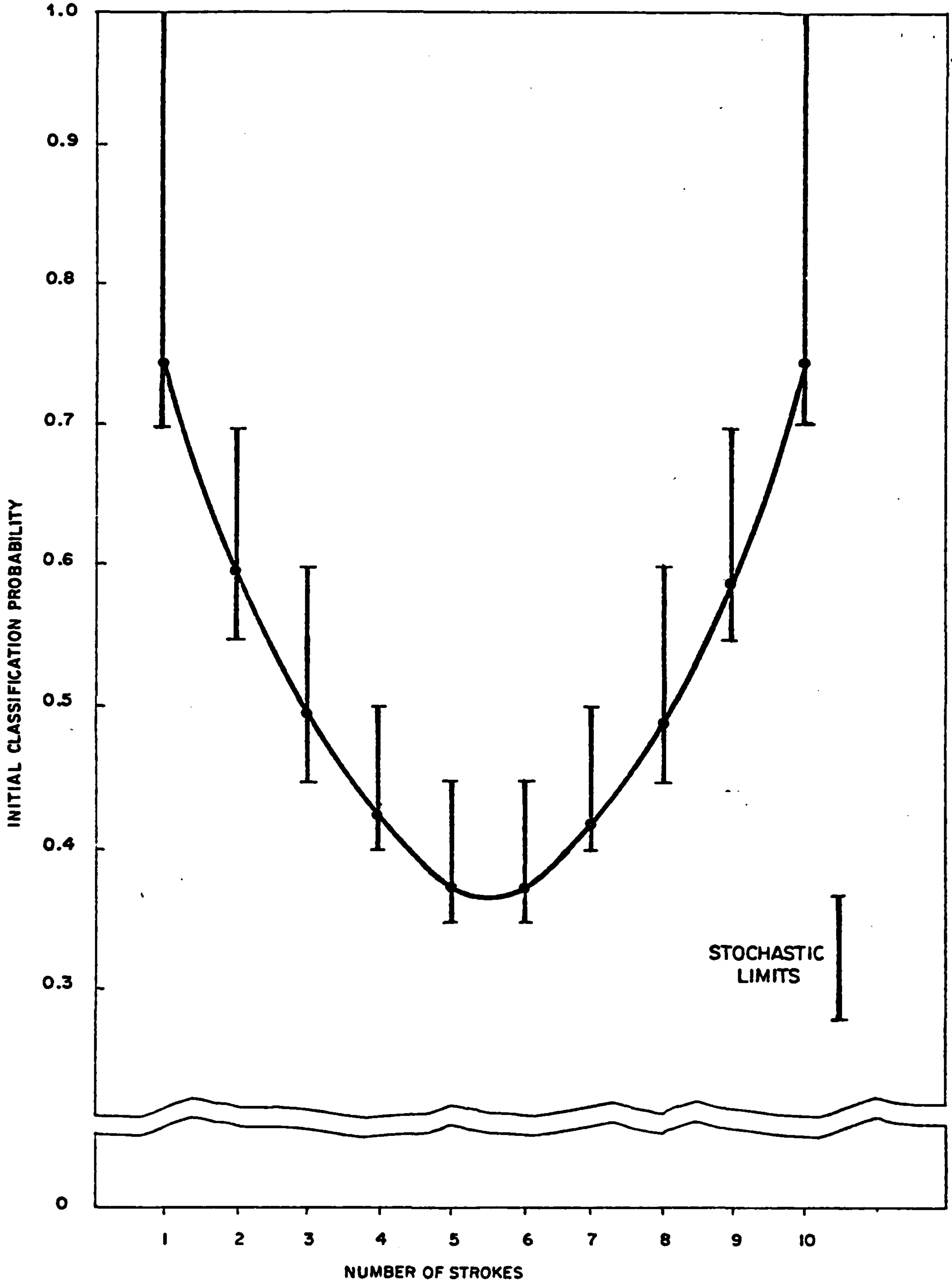

FIGURE 2-5. INITIAL CLASSIFICATION PROBABILITY AS A FUNCTION OF THE NUMBER OF STROKES IN GENERATED TARGET.

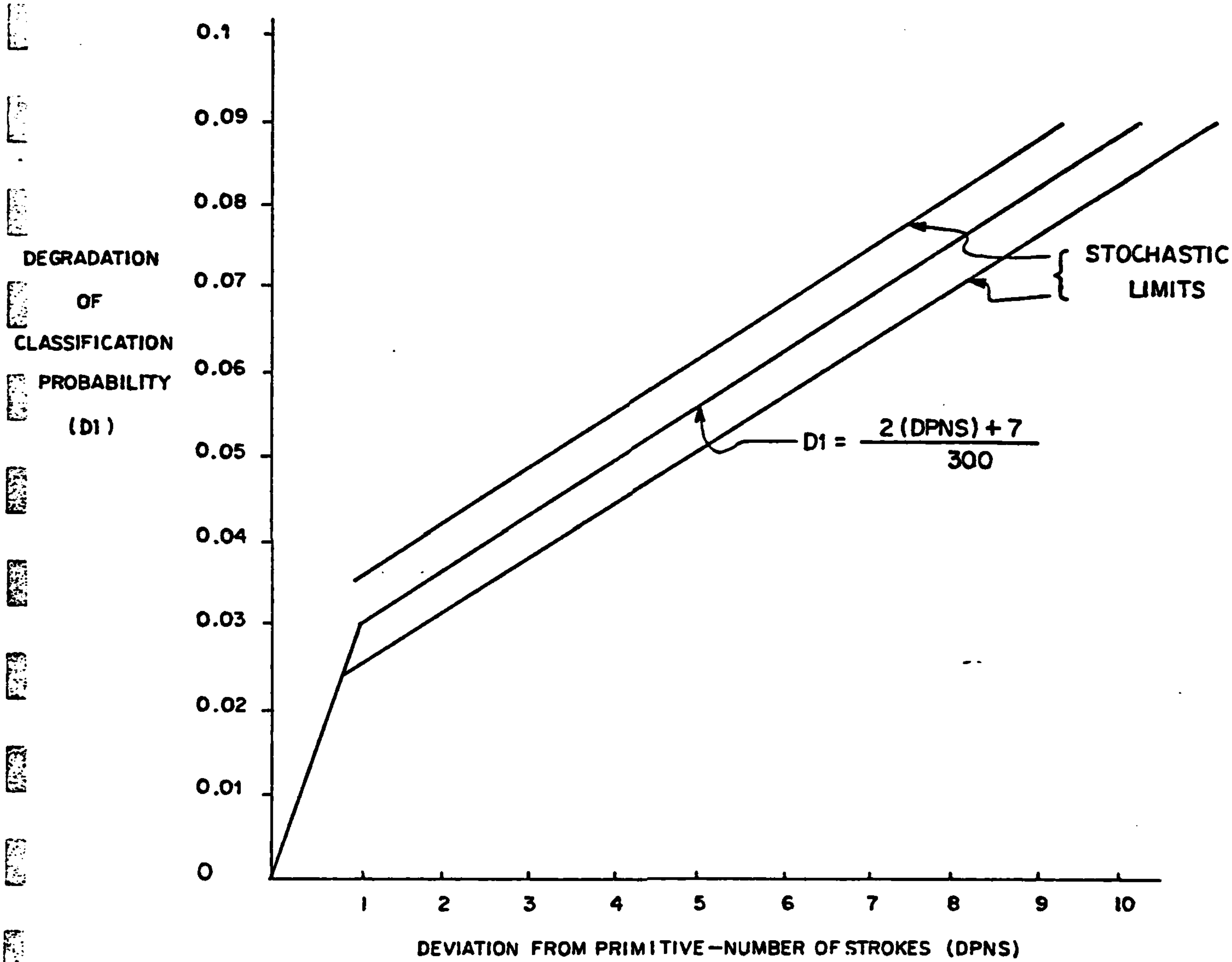

FIGURE 2-6. DEGRADATION OF CLASSIFICATION PROBABILITY AS A FUNCTION OF DEVIATION IN NUMBER OF STROKES.

Hake reported a number of studies which support the contention of modified association value for slanted (rotated) figures.

In the simulation, the results of Arnoult (1960) were relied on to provide the basic function. Arnoult varied 10 nonsense shapes over eight angular positions and asked subjects for same or different judgments when the rotated shape was compared to a standard. Arnoult's data were smoothed and rescaled. However, the shape of the Arnoult curve was closely approximated. The resultant function is shown in Figure 2-7.

The function, deviation from length of main stroke (Figure 2-8), presupposes that subjective response alternatives increase as the target size decreases so that the match between current stimulus and its mental template in memory is more difficult. That is, guessing must be instituted until a correct "match" between current stimulus-input and memory-pattern has been achieved when very small targets are involved. The constraints that preexist in the real environment need to be discovered through successive trial-and-error episodes, until stimulus features correspond to predefined pattern features sufficiently that the intended recognition response is obtained.

Bruns, Bittner, and Stevenson (1972) in a dynamic television identification task concluded that "Target effects were primarily related to target size expressed either as target area or target diagonal." The data of Bruns, Bittner, and Stevenson were employed to derive the required function (Figure 2-8). Their data indicated an almost linear relationship ($r = .98$) between slant range identification and target diagonal with a slant range identification ratio of about 6:1 for "small" as compared with "larger" targets.

The fourth function (Figure 2-9), deviation in curvature, was similarly based on the contention that deviation from an anticipated image will decrease classification accuracy.

Unfortunately, no studies were identified by the developers of the simulation which reported data relative to the effect of curvature on recognition accuracy. Accordingly, the Figure 2-9 curve was derived on the basis of the best professional judgment of the developers of the simulation.

The recognition module also considers context, operator proficiency, and stress. The context effect was based on the work of Miller, Heise, and Lichten (1951) who reported a range of context effects of about 30 percent. To simulate this effect, a random number equiprobable in the range 0 to .30 is drawn and applied. Operator proficiency and the stress effect are simulated in much the same manner as for other models developed by Siegel and his coworkers.

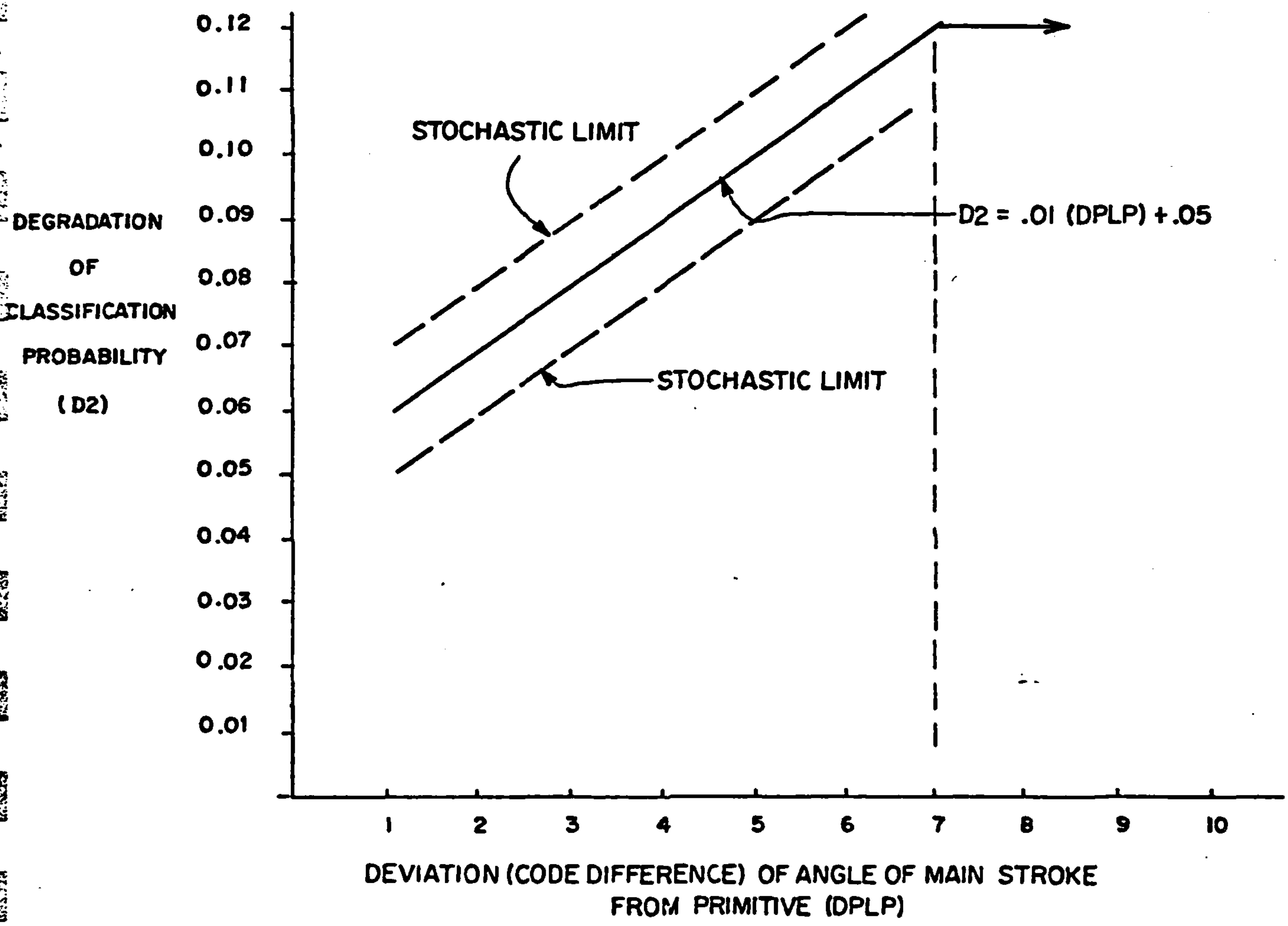

FIGURE 2-7. DEGRADATION OF CLASSIFICATION PROBABILITY AS A FUNCTION OF DEVIATION FROM ANGLE OF MAIN STROKE.

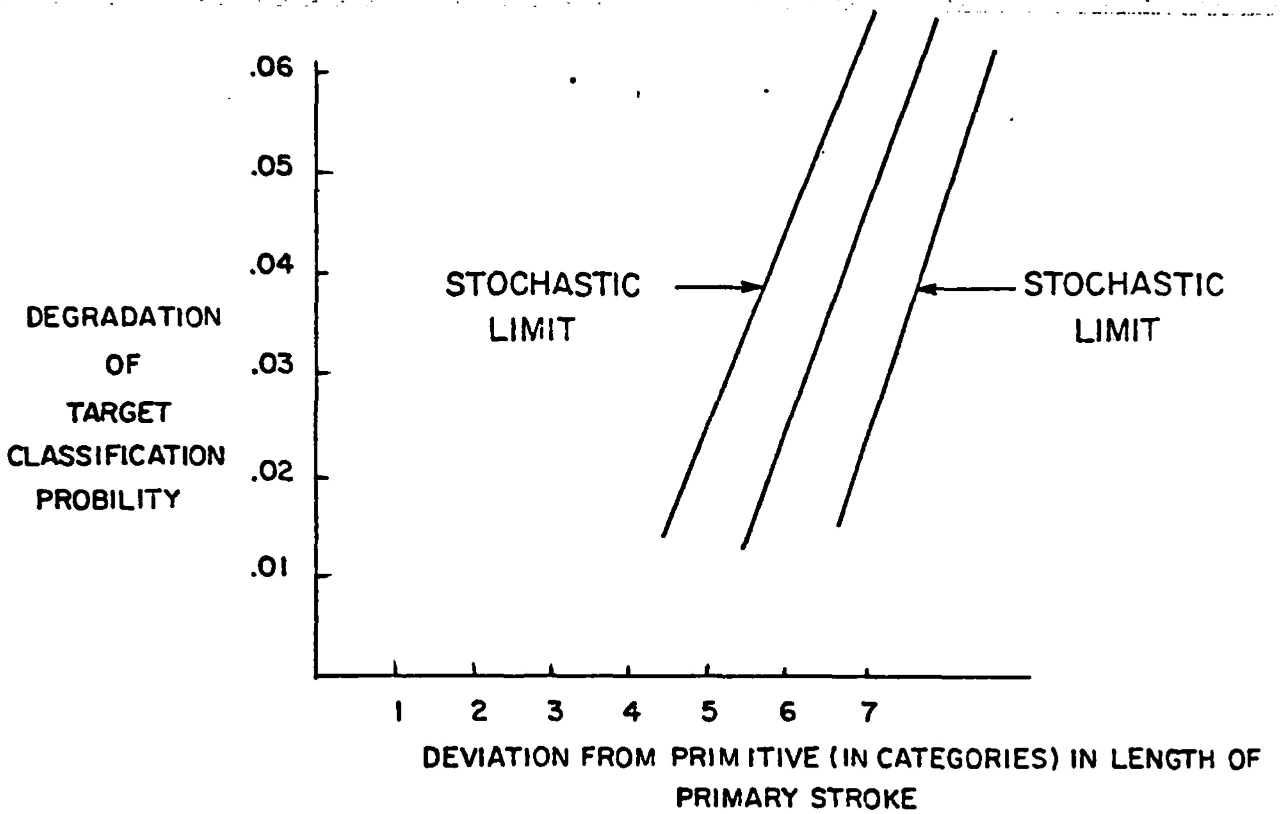

FIGURE 2-8. DEGRADATION OF CLASSIFICATION PROBABILITY AS A FUNCTION OF DEVIATION FROM LENGTH OF MAIN STROKE.

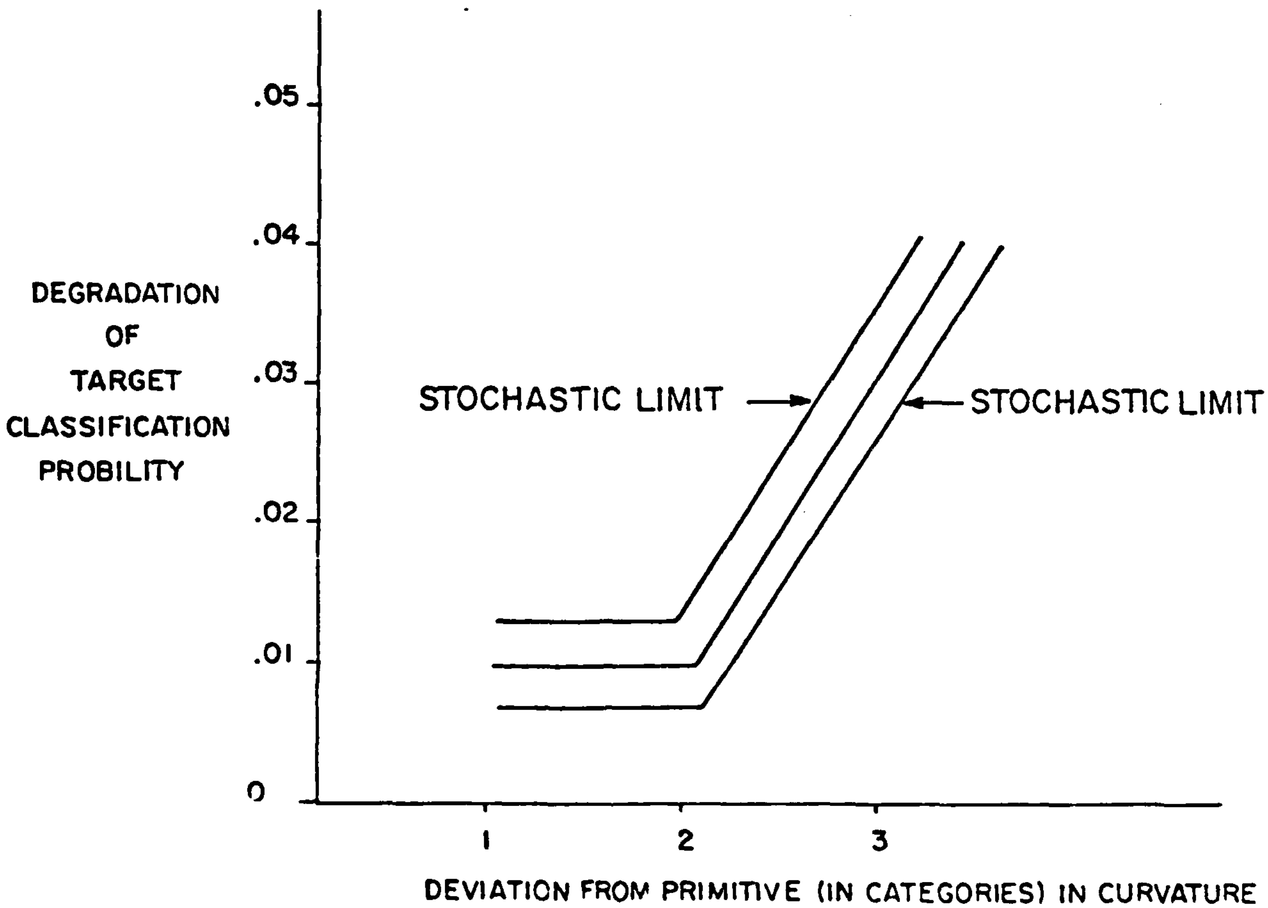

FIGURE 2-9. DEGRADATION OF CLASSIFICATION PROBABILITY AS A FUNCTION OF DEVIATION IN CURVATURE OF MAIN CURVED LINES.

The logic flow for the total recognition subroutine is presented as Figure 2-10.

Discussion of Simulations Described Above

Each of the above described simulator modules, as for most behaviorally oriented simulations, is based on current behavioral theory. They all attempt to quantify that theory and set it in a form suitable for computer implementation. Four relatively discrete modules were selected so as to provide some insight into the scope of some of the simulations that have already been developed and of the dynamic character of such simulations.

Such modules, when embedded within a total behavioral or person-machine system simulation, provide a rather sophisticated method for system evaluation. The decision module and the recognition module formed part of a total simulation developed for the Air Force (Siegel, Wolf, & Williams, 1978). This total model sought to simulate the behavior of the image interpretion operator of an advanced electronic imagery system. The motivation module formed a part of the Army simulation of exercise control systems called NETMAN (Siegel, Leahy, & Wolf, 1977). The operator physical capability simulation formed a part of a Navy simulation of the performance of crews of intermediate size (4-20 men) stations (Siegel, Wolf, & Cosentino, 1971). Accordingly, the contention may be advanced that such modeling has been found useful by each of the services in a variety of contexts.

Quite obviously, such modeling would find itself of interest in a variety of additional Army simulations. Offensive, defensive, and tactical battle models depend on the ability of the soldier to perform mental/physical operations such as those encompassed by the simulations described above. For example, mechanized infantry, tank crews, and FIST must recognize and classify targets. Decision making is inherent in the jobs of every soldier at every level. The effects of stress on performance become particularly relevant when one considers the anticipated character of future warfare.

Table 2-3 identifies 25 different current military models which possess human resources implications and the types of behavioral subroutines which, if included in these models, would lend increased veridicality to them.

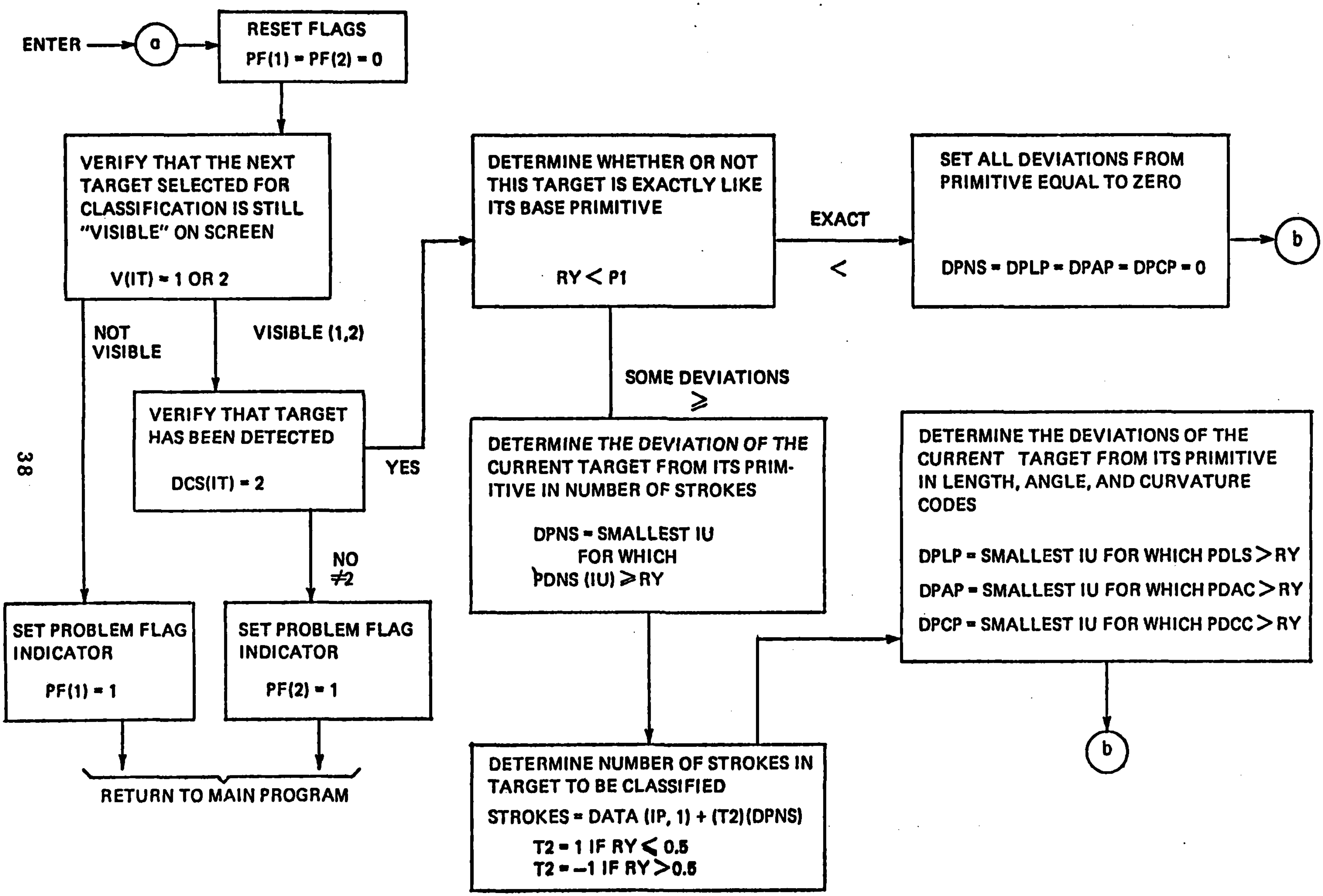

FIGURE 2-10. FLOW LOGIC FOR VISUAL RECOGNITION MODULE.

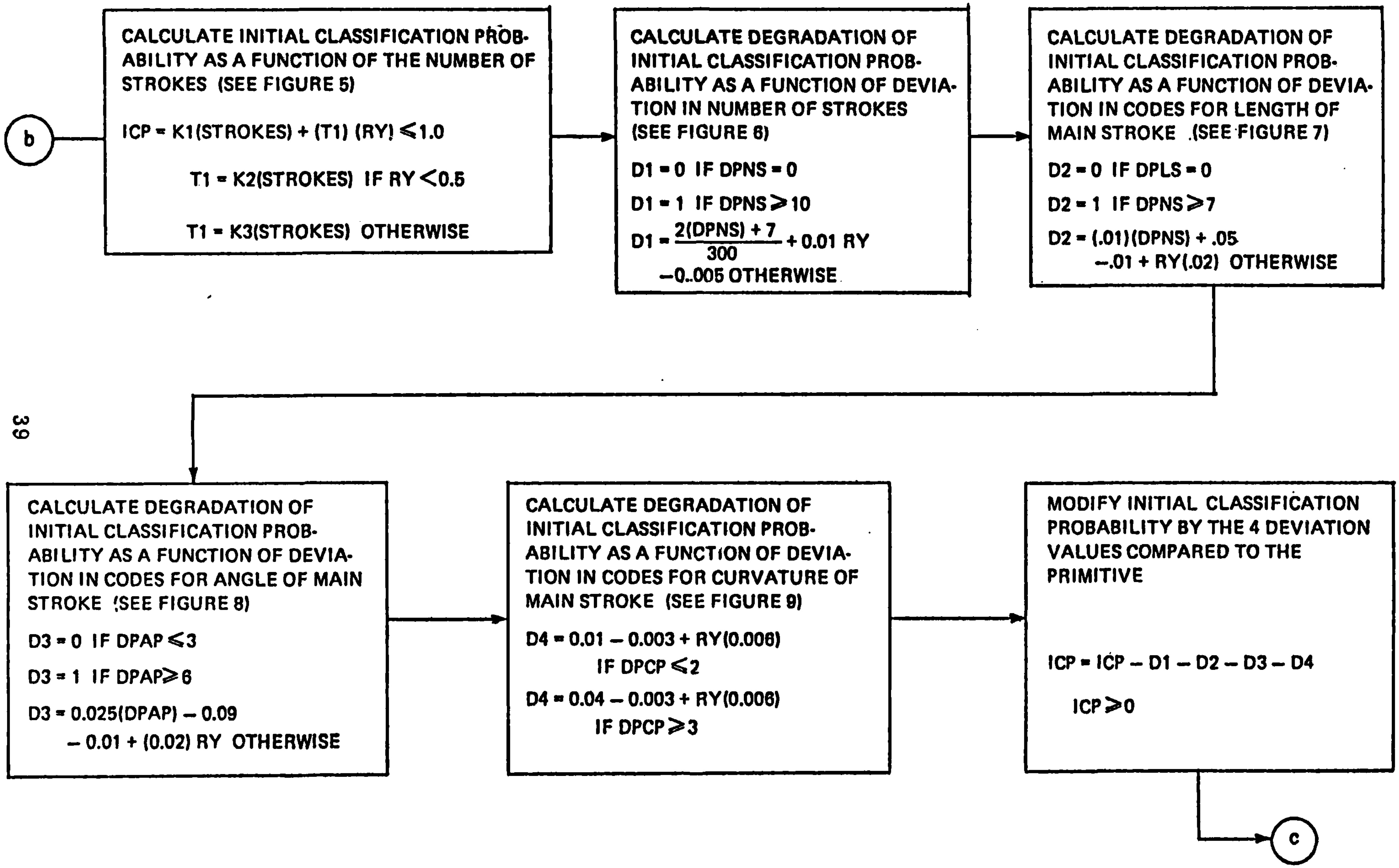

FIGURE 2-10. FLOW LOGIC FOR VISUAL RECOGNITION MODULE. (CONT'D)

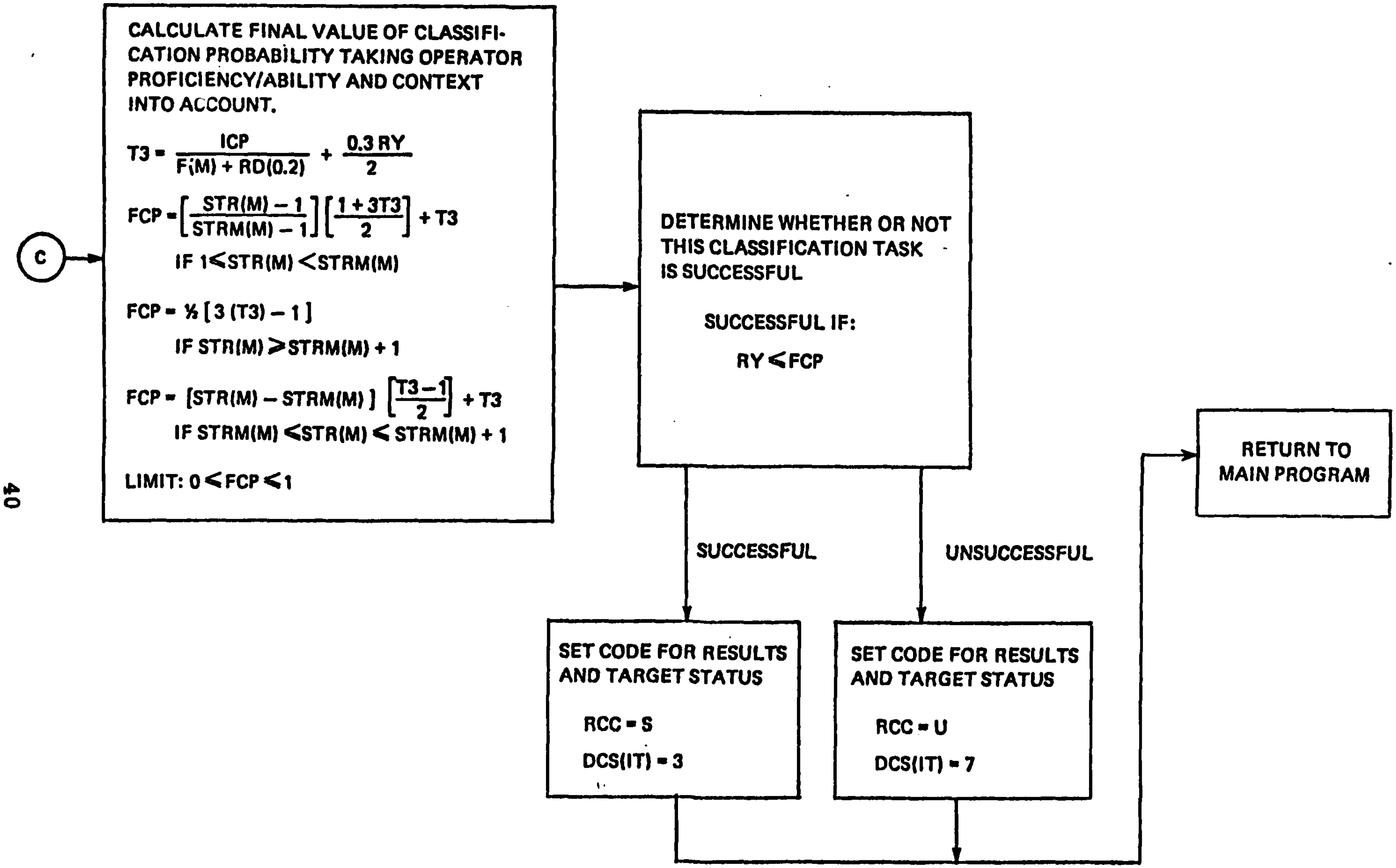

FIGURE 2-10. FLOW LOGIC FOR VISUAL RECOGNITION MODULE. (CONT'D)

Table 2-3

Sample Current Military Behavioral Simulation Models and Potential Behavioral Subroutines for These Models

MODEL	AUTHOR(S) and DATE	PURPOSE	CONTENT	POTENTIAL BEHAVIORAL SUBROUTINES	COMMENTS
1. Aircrew manning requirements	Lozano, P. A. (1980)	Represent major attributes of a squadron or SAC jet tanker aircraft and crewman for the purpose of studying aircrew manning requirements for peacetime surge and wartime tanker requirements.	Number of aircraft, crews, number and type of missions, rest breaks, leave, briefings, mission schedules.	Maintenance skill level, pilot/crew skill level, fatigue.	The program schedules missions and the output shows how the system is performing by accumulating cancellations, flying times, and delays. A log is provided of every change in status of every man and every aircraft.
2. LOGATAK II (Logistics System Attack Model II for Analysis of Transportation, Network Distribution and Interdiction)	Burger, R. T. (1980)	Measure workloads in a transportation system, analyze vehicle and carrier requirements in a logistic system, analyze operations of a distribution system, and assess impact of interdiction on a logistic distribution system.	Link and terminal specifications, mode, length, rate of travel, capacity, number of loading docks, time to rebuild, number and location of vehicles, time demands, priority of units, stockage at supply points, and attacks.	Personnel characteristics.	Provides supply status (quantity ordered, received, due-in), transportation status (network characteristics and loads, throughput, queue buildups, vehicle utilization), and attack results.
3. Aggregate Pilot Pipeline Model	Air Force Institute of Technology (1980)	Document recruitment, training, and allocation of Air Force pilots.	Authorized flying hours aircraft availability, projected pilot strength levels.	Pilot skill, learning curves.	Determines training requirements for use in establishing undergraduate pilot training instructors and recruiting quotas.
4. SAMPS (Shore Activity Manpower Planning Systems)	Bres, E.S. (1980)	Determine recruiting requirements based on manpower goals and promotion planning.	Initial period on-board figures, manpower goals based on workload planning data by center and time period.	Recruit satisfaction.	
5. RIO (Recruit Input Optimization)	Silverman, J. (1980)	Prescribe recruitment into the Navy to meet demands of the petty officer corps and budget constraints.	Number of years to the planning horizon, end inventory of apprenticeship group, previous recruitment, number of promotions in the petty officer corps, desired recruitment into apprenticeship group, desired inventory in apprenticeship group, number of personnel lost from apprenticeship group, and number of personnel gained to apprenticeship group.	Training, skill level, emotional stability, leadership.	Forecasts the number of recruits.
6. FAST (Force Analysis and Simulation Technique)	Silverman, J., (1980)	Project the effects of personnel policies, manpower requirements, and budgetory constraints on the size of the enlisted force structure in the Navy.	Pay grades, length of service by rating, desired future force levels, policy parameters (e.g., separation and accession, promotion, grade management, career field management).	Leadership, goal orientation, morale, satisfaction.	A set of pay grades by length of service by rating by fiscal year.

Table 2-3 (cont.)

MODEL	AUTHOR(S) and DATE	PURPOSE	CONTENT	POTENTIAL BEHAVIORAL SUBROUTINES	COMMENTS
7. CAMRIS (Computer-Assisted Military Retirement Information System)	Johnson, P. S. (1980)	Provide military personnel with financial planning counseling	Retirement pay, survivor benefit plan deductions, spouse's wages, federal income tax withholding, retiree's wages from other employment, retirement income tax credit.	Self control decision making, life style.	Provides information on retiree's financial status, retiree's benefits, and monetary privileges in a balance sheet arrangement.
8. Predicting Military Reserve Show Rate	Trinnaman, J. E. (1980)	Provide estimates of the availability for pretrained manpower for mobilization.	Manpower pool, manpower profile, mandatory exemptions, and exemption/delay/restricted assignment.	Training, proficiency, need for affiliation, family ties.	Provides mobilization show rates for each reserve component, i.e., estimates the number of reserve personnel who would be employable in the event of mobilization, and estimates of the four groups requiring management initiatives to assure their availability (delay, restricted assignments, failure to report, and training pipeline).
9. TRAMOD (Training Requirements Analysis Model)	Goclowski, J. (1980)	Assist-developing training programs on the basis of task, time, and resource criteria.	Task data, e.g., criticality, learning difficulty, frequency, psychomotor level, and cognitive level; task training mode, method, medium; time required to train person to perform task (in school or on-the-job).	Training, proficiency, skill level, intellective level.	The training program, the task blocks and training plan.
10. DSFM (Dynamic Student Flow Model)	Wilkinson, W. L. (1980)	Produce solutions with the maximum throughput of flight students with the minimum time to train.	Pilot training rates for three-four years, list of training phases and their sequence, location of phase and aircraft involved, weeks to train, attrition rate, total flight time per phase, percentage of flyable weather by month, daylight hours by month, student load and pools by phase, and student input schedule.	Training, proficiency, skill level, intellective ability.	Provides informational requirements relative to the various inputs.
11. SAINT (System Analysis of Integral Networks of Tasks)	Seifert, D. J., Hann, R. L., & Chubb, G. P. (1980)	Analyze man-machine systems, assess the effects of component characteristics of the system on overall system performance, generate system performance estimates.	Tasks performed, precedence relations among tasks, flow of information through the system, and the effects of environmental stressors on task performance.	Fatigue, stress, skill level.	Provides summary information on resource utilization, task performance, state variable status, and other system performance measures.
12. PERCAM (Land Combat Performance and Cost Analysis Model)	Burt, M. P., & Valrand, C. B. (1980)	Determine system performance and cost effectiveness, evaluate weapon systems through modeling of attacker and defender (e.g., defender can be anything from [illegible]	Descriptions of attackers and defenders, geometry of the encounter, and system costs.	Number of attackers/defenders, communications, leadership, coordination.	Provides summary of engagement outcome, average number of attackers, defenders, targets destroyed, the average engagement cost to each force, and the engagement cost effectiveness ratio.

Table 2-3 (cont.)

MODEL	AUTHOR(S) and DATE	PURPOSE	CONTENT	POTENTIAL BEHAVIORAL SUBROUTINES	COMMENTS
13. Human Reliability Prediction	LaSala, K. P. (1980)	Predict and demonstrate system effectiveness of combined man-machine systems, considering mission reliability and availability, human and equipment MTBF, and MTTR.	Number of persons in rank and specialty, body weight, proficiency, work pace, physical capability, capability after a full day of work, equipment and failure rate, repair time, and number of persons required to repair.	Skill level, fatigue, stress, training.	Program calculates human reliability, availability, and MTTR; equipment reliability, availability, and MTTR; system reliability, availability, and MTTR; as well as stress, fatigue, percent of work completed, percent needing touchup, and time for completion.
14. Prediction of Target Travel During Missile Flight.	Torre, J. P., Jr. (1980)	Determine efficacy of a gunner's decision if and when to fire at a target based on his estimate of target's angular velocity (distance and speed), his knowledge of the missile's time of flight, and perceived angular size of the gap the target must cross to reach concealment.	Target speed, gap (distance target must cross to reach concealment), time of flight, target range, time to practice runs, decision ability, decision time, practice level, viewing distance, physical fatigue, and stress.	Training, proficiency, decision making ability, fatigue, stress.	Provides measures of the gunner's ability to estimate target's future travel and measures gunner's ability to decide whether or not to fire.
15. HELMATES (A Hellfire Engagement)	DARCOM--Material Systems Analysis Activity (1980)	Assess system effectiveness and survivability of helicopter weapon systems employing advanced development concepts of helicopter launched missiles against mixed armor and air defense threat.	Performance times and effectiveness for each participant and engagement rule options, locations and ranges between participants.	Training, proficiency, fatigue.	Determines probabilities of defeat of the attack helicopter, forward observer or scout helicopter, and tank; also determines expected event times, detection, and reaction time intervals.
16. Minefield Tactical Deterrence Model	Schecter, G. (1980)	Quantify the tactical deterrent effects of mine systems and advanced mine concepts used in arms combat engagements; to measure the deterrent effects produced by the interactions of an attacker's tactical objectives, his estimate of the force required to win, and the observed casualties during the attack.	Number of rounds to be fired per weapon type, hit probabilities, direct suppression, detection probability, target priority, probability of being suppressed by indirect fire, tactics, terrain, climatic conditions, mission requirements, risk behavior characteristics, and mission value over the set of missions.	Training, skill, fatigue, stress, proficiency, decision making.	Provides number of reduced casualties due to attacker deterrence.
17. TXM (Tank Exchange Model)	Olson, W.K. (1980)	Examine differences in tank survivability and kill power through analysis of vulnerability and lethality differences in tank candidates.	Gunnery performance: firing times and add on dispersions; terrain root-mean square and speed for all candidates; platform velocity, and aspect angle.	Training, fatigue, stress, psychomotor ability.	Provides indications of casualties, ammunition expenditures, battle termination cause, effectiveness, average time of loss, position of loss, and candidate effectiveness.

Table 2-3 (cont.)

MODEL	AUTHOR(S) and DATE	PURPOSE	CONTENT	POTENTIAL BEHAVIORAL SUBROUTINES	COMMENTS
18. AMSWAG (AMSAA War Game Model)	Orlov, R.D. (1980)	A war game of battalion combat situations of ground combat forces.	Terrain, location, velocity, intervisibility, minefield, vulnerability, weapon and round estimates for each firer-target combination.	Decision making ability, training, intellective ability.	Provides total vehicle and personnel losses for each side, ranges between forces, vehicle exchange ratios, vehicle force ratios (surviving attacker vehicles/surviving defender vehicles), game time, list of units which have been killed, number of kills for each firer type versus target type, number of survivors of each type, and the ammunition left.
19. ALPOS (Avionics Laboratory Predictive Operation and Support Cost Model)	Turek, J.P. (1980)	Provide the capability to predict avionics operations and support costs in the conceptual/early design phases.	Variables include unit price, volume, weight, components count and density, power dissipation, component type, component technology utilization factor and a bit factor, indicator variables for command, aircraft type, and avionics area. Cost equations were developed for these elements.	Personnel skill, intellective ability, training, motivation.	Provides the calculated factors and a description of costs. Cost summations accumulate costs on an annual basis and a nonrecurring basis for spaces and support equipment. Support costs include maintenance plus ancillary efforts to support the maintenance cost equations.
20. Assessing WRSK Capability	Rasmussen, R., & Stover, W. (1980)	Evaluate the capability of war readiness spaces kit (WRSK) to support a wartime flying hour program.	Organizational and field maintenance demand rate, base repair capability, base repair turnaround time, quantity per aircraft, remove-repair-replace status, flying hour program, and shortages in the WRSK.	Maintenance skill, training, fatigue, stress.	A graph is provided which compares the required flying hour program to the predicted capability.
21. ATAGAS (Air-to-Air Gunnery Assessment)	Staggs, D. (1980)	Evaluate system success in terms of the gunfire control system, to analyze air-to-air gunnery from hit and miss data.	Direction of air before commencing fire.	Training, proficiency, psychomotor ability, fatigue.	Hit and miss data.
22. VECTOR-2 (Theatre Battle Model)	Weintraub, A.C. (1980)	Study the dynamics of weapon systems interactions in conventional theatre-level ground and air campaigns with battalion-level resolution.	Performance, environment, tactics; other input data include direct and indirect fire, command and control, intelligence, communications, and logistics.	Communications, cooperation, leadership, training.	Provides tabulations of unit positions, ammunition expenditures, and casualties by types of firing causing them.
23. TARTARU IV (Wargaming Model)	U.S. Army Concepts Analysis Agency (1980)	Game conventional land combat, close air support, and tactical nuclear weapons.	Terrain data, unit descriptions (mission, location, and strength), weapon class effectiveness, attrition, movement, suppression, air strike data, fuel and ammunition distribution, and weapon firepower potential.	Decision making ability, training, intellective ability.	Generates reports of personnel and equipment losses, ammunition expenditures, and data for a graphic display of the battlefield to a map scale.

Table 2-3 (cont.)

MODEL	AUTHOR(S) and DATE	PURPOSE	CONTENT	POTENTIAL BEHAVIORAL SUBROUTINES	COMMENTS
24. CARMONETTE (Gaming for Division Restructuring)	Bailey, T.J. (1980)	Examine combat effectiveness of four alternate battalion task forces in various combat scenarios, through the modeling of two opposing forces; the basic activities modeled are movement, target acquisition, direct fire engagement, intelligence, fire support, air defense, and air operations.	Weapon characteristics and performance, terrain elevation, vegetation height, cover index, concealment index, cross country mobility index, road mobility index, mobility data, und sensor data.	Decision making, ability, training, comprehension, proficiency, stress tolerance.	Displays the combat actions simulated graphically, including: unit movement, direct fire pairings, artillery, morter firings, casualty assessment, and mount/dismount of passengers from carrier units.
25. CSSM (Combat System Survivability Model)	Schilling, W. (1980)	Evaluate the survivability of friendly combat systems and the vulnerability of hostile combat systems.	The various modules can be exercised independently or in conjunction to conduct varying types of analyses; the input data is dependent on the modules used in the analysis.	Training, stress, fatigue.	Provides a list of potential targets, target selection, weapon aim points, probability of damage due to weapon characteristics, damage to attacked personnel, materiel, and targets.
26. PERFECT (Performance effectiveness prediction)	Siegel, A.I., Wolf, J.J., Ozkaptan, H., & Schorn, A.M. (1980)	Predict performance degradation due to continuous operations effects.	Terrain advantage, force ratios, weapons availability, light level, time duration of operation, proficiency, time without sleep, and others.	--	Predict performance effectiveness and degradation over time for various types of Army unit under various combat conditions.

III. PROBLEMS IN MODEL DESIGN

Selection of Type of Model

The first question with which the model developer needs to concern himself involves the type of model he requires. This question is basic and subsequent model design decisions will depend on the answer. First, consider that behavioral simulation models may be conceived as falling into one of four classes:

		Performance	
		Functional	Psycho-logical
Driver	Tasks or Events		
	Time		

Models may be driven on the basis of events (tasks) or on the basis of unit time increments. Performance may be functionally represented or it may be constrained on the basis of psychological (human oriented) constructs.

Drivers

Task or event driven simulations sequentially simulate the performance of the subtasks of a given task or the events to be performed during a specified duty segment. They are most applicable when the subtask or event sequence is to some extent known and fixed. The Siegel - Wolf (1969) model is an example of an event driven model. In such a model, time may be accumulated on the basis of the time for event performance but the event performance drives the time and not the reverse.

Event driven models may be further subcategorized as "event oriented" or "activity oriented." In the event oriented advance, single events trigger partial state-change routines. In activity advance, a complete series of state changes is triggered at the time all conditions are satisfied to permit an activity to start or stop.

Time driven simulations are based on the passage of time. They advance on the basis of some internal clock. When a given time is reached, the system state is simulated and the results are recorded. There need be no event list or associated processing.

The time advance approach is less preferable if there are many periods when no events occur. Event advance procedures will generally be preferable when the added calculations for the event list do not exceed the overhead involved in time advance (uneventful periods). If events occur on a fairly regular basis, time advance periods can be established in a way that minimizes the chance of advancing to periods of inactivity--in which cases time advance is to be preferred.

Performance

Functional models simulate performance directly. They do not concern themselves with higher order constructs or intervening variables. Most engineering models would probably fall into this category. A personnel utilization model (Feiler, 1971) typifies this type of model. The general scheme for Feiler's model is shown in Figure 3-1. In this model, the head nurse reports to work and "proceeds" directly to her routine tasks. From time-to-time, she is interrupted by nonroutine tasks such as responding to phone calls and patient incidents. Note that activities are simulated as events without the superimposition of higher order constructs and that the model is event driven.

Psychological models rely on constructs such as stress, aspiration, etc. as the basis for the simulation. These constructs are considered interactively and in a sophisticated manner. The four simulations described in Chapter II under the heading of "Specific Behavioral Traits Modeled and Their Logic" represent examples of this type of simulation.

Quite obviously, there may be mixed models with different subroutines representing different classes of simulation. The functional-task driven category probably represents the easiest (quickest) type of model to develop. However, functional-task models may lack richness. They will answer the "Does it work?" question but may provide barren answers to the "Why does it work?" or "How to make it work better?" questions.

The functional-time driven category is next on the hierarchy of construction difficulty. Models in this class provide no more insight than event driven models.

Psychological models are more difficult to develop but are believed to represent a necessary ingredient in any model which purports to simulate a system in which human attributes exert salient effects. Models

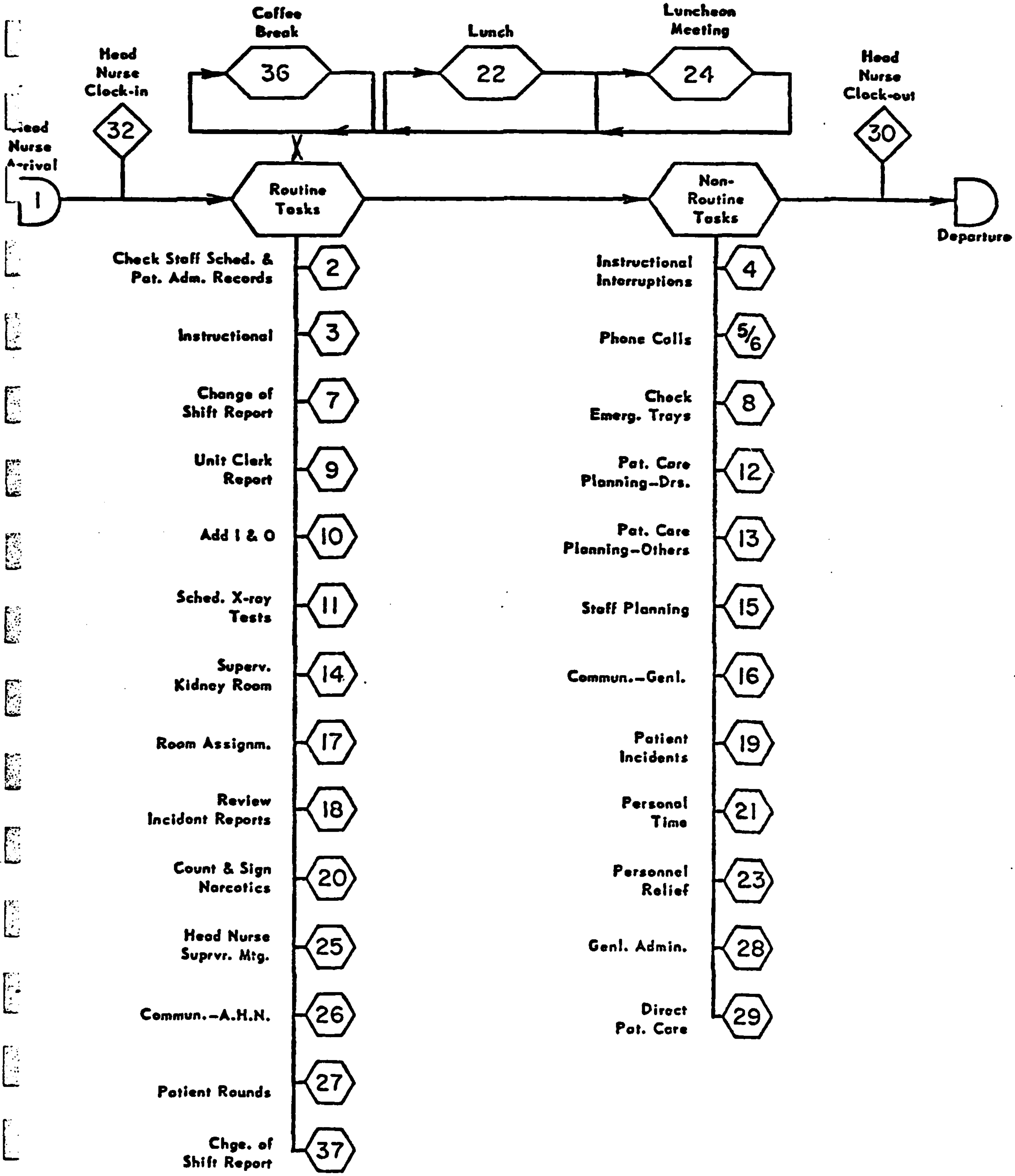

FIGURE 3-1. HEAD NURSE SIMULATION MODEL (U.C.L.A. HOSPITAL) OF FEILER (1971).

of person-equipment systems which fail to consider human behavioral effects cannot be held to represent fully the system being modeled.

Both event driven and time driven psychological models provide insight into a wide variety of questions relative to system trade offs and optimization. However, models in these classes are the most difficult and time consuming to construct

Data Requirements and Data Availability

The ultimate success of a behavioral simulation model, like any computer simulation model, depends on the validity of the input data utilized. A model may be fully acceptable in terms of its constructs but may be unusable because the input data required for implementing the constructs are not available or are not at a required level of accuracy. This applies both to the numerical constants utilized as part of the model program as well as to the parameter, mission, and operator data provided as input to each model run.

While a number of data banks (e.g., Munger & Smith, 1962) are available, such data banks are remarkably barren in regard to higher order human processes and abilities. Moreover, in view of individual differences, normative data based on general populations are often of little use to a behavioral simulation. This input data relevancy consideration is particularly pertinent to simulations of Army personnel. Quite obviously, there is little sense in developing a sophisticated simulation only to find later that the required input data are either meager or lacking. Too often the model designer approaches his model development/opportunities with little concern over the availability of input data. Such concerns are considered by the model developer to be mundane and are left for the model user. But, the model user wants model output results and often has little time, patience, or ability to develop or obtain esoteric, behaviorally oriented data.

Level of Data Detail

Assuming the availability of the required input data, how much burden does the model's requirements place on the user? Some models require long lists of appropriately coded input information. The input chore can be further magnified by a programmer who, with commendable computer system expertise but little human factors insight, may require features such as right justification of input or esoteric and fixed card formatting. Other model designers, are more considerate and their models are more tolerant. Input data are stored and only modifications to prestored values are required of the user; free format entry is permitted and the amount of required input data is limited.

There is obviously some upper limit on the amount of time that the user wishes to spend on preparing input data. To promote use and practicality, initial data preparation must be reasonable for initial preparation, reruns, and changes of missions and parameters. Use of interactive terminals on a conversational basis promotes this end.

Programming

Programming a behavioral simulation represents the translation of the model's logic to a form that is usable by a specific digital computer. In some cases, the person who develops the model's logic also performs the translation. In other cases, an independent computer programmer may be used. Provided that a fully detailed set of program specifications or detailed flow chart has been developed, there seems to be little advantage of one procedure over the other. Table 3-1 presents the advantages of each type of assignment to the programming. Of course, if the person who developed the logic has little or no programming ability, there is no choice other than the assignment of a professional programmer to the work.

Table 3-1

Comparison of Advantages of Assigning Model Developer or Programmer to Model Programming

Advantages of Assigning Model Developer	Advantages of Assigning Professional Programmer
1. Fewer errors in representation (flow chart misinterpretation)	1. More efficient final program and system use
2. Logic changes needed to facilitate programming can be made "on-the-spot"	2. Time savings
3. Avoids developer-programmer communication difficulties	3. Less costly
4. Results in better user input formats	4. Does not divert needed "modelist" talent to a task which can be done by others
	5. Probably results in fewer program "bugs"

Regardless of the approach adopted, errors do occur in virtually all programming. We are not concerned as much with coding errors which will be uncovered by normal check procedures as with logic misrepresentation and/or misinterpretations. These are sometimes difficult to check and will occasionally remain undetected even after an extensive program check.

When these become evident during model application, considerable confusion can result. Air Force studies have shown that corrections of program design errors cost only about 10 percent as much to make during the design phase as those not detected until the program is in a maintenance stage. The model user may be unfamiliar with both the logic and the programming details. Accordingly, the user will find it difficult to implement the required adjustments. The result may be that he will be forced to abandon his anticipated use of the model.

A word on trends in the computer language currently selected for models is in order. The DoD Catalog of Logistics Models (Air Force Institute of Technology, 1980) reported the programming language for 174 models. By far, the largest single language used was FORTRAN in its various forms (used in 134 of the 174 entries). Other general purpose languages, i.e., standard compilers, were popularly used as follows:

COBOL	11
BASIC	5
PL-1	5
PASCAL	1
Total	22

Of considerable interest, and somewhat surprising, is the fact that relatively few models utilized the special programming languages specifically developed to facilitate simulation programming efforts:

SIMSCRIPT	8	
DYNAMO	5	problem oriented languages
GPSS	3	
GASP	1	
SPSS	1	
Total	18	

These data represent the selection of FORTRAN in about 77 percent of logistics models, other standard languages in about 13 percent, and use of a "simulation" language in about 10 percent of the cases. A description of the various simulation languages, together with an analysis of the process of reasoning an analyst might use in language selection is given in Emshoff and Sisson (1970). The significant efforts in simulation language developments in the 1960s have had comparatively little real impact on the model development community.

Transportability

Transportability refers to the capability to transfer a completed and tested model to users other than the original developer(s). If the model user and model developer are one and the same person, then transportability is, of course, not a problem. However, if the model is to be employed by users other than the original developer, the problem of proper support to the user(s) must be handled as it would be with any software package. The way to avoid such problems is to anticipate them at the outset and to provide the tools that facilitate a multiuser situation. Some ground rules for avoiding transfer problems are:

- Program in a high-order language which is generally known (e.g., FORTRAN IV, BASIC); avoid machine and assembly languages
- Fully comment the program
- Structure the program
- Program for a computer system which is readily available and possesses adequate peripherals, terminals, and storage capacity
- Provide for planned program maintenance, i.e., offer a service to correct errors
- Make arrangements for providing each release of the program in machine readable form to all users; unless the number of users is small, do not plan on special modification of the model to meet the needs of some specific users
- Date released material and assign a release number to it
- Provide a fully detailed logic description of the model
- Provide a fully detailed users' manual including, but not limited to, program overview description, limits, variable list, program list, operating instructions, examples of input formats and output results, program control instructions, and glossary
- Try to avoid calling from system libraries subroutines which are not generally available in most computer libraries.

- Prepare training materials and present formal and hands-on training when delivering the model to each user; incremental training may also be required for new releases and for users' replacement personnel
- Provide a mechanism by which users can call or write to describe and obtain help on problems and can suggest future model enhancements; this "home office" support may involve over the phone consultations and/or visits to user facilities
- Provide full output interpretation instructions
- Document user problems as they occur so that the users' manual and associated materials may be updated
- Pretest all model releases and user materials on a sample which represents the total user population before distributing the materials; prearranged test sites (test users) are often selected to facilitate this process.

Model Validation

Model validation may represent the most talked about and least understood aspect of model development. One aspect of the problem may rest in the confusion brought about by the application of test validation constructs to model validation. Quite fortunately, models are not psychometric tests and the test development paradigm may not be applicable. We argued earlier that the principal test of any behavioral model is its practical utility. This is not to say that some type of validation is not necessary. The decision maker cannot arrive at a proper decision on the basis of invalid data.

Relative to the validation problem, Milton Friedman set the stage in 1953 when he argued that modelists have missed the point by focusing on the internal constructs of a model. Friedman contended that the validity of a model rests not on its assumptions and constructs, but on its ability to predict dependent variables. Relative to construct validation, Friedman wrote:

> ...This widely held view is fundamentally wrong and productive of much mischief. Far from providing an easier means for sifting valid from

> invalid hypotheses, it only confuses the issue, promotes misunderstanding about the significance of empirical evidence for economic theory, produces a misdirection of much intellectual effort devoted to the development of consensus on tentative hypotheses...[1953, p. 14].

Hatch (1971) reviewed the confusion among modelists about the validation problem. In a discussion of "How do you know it is valid?" Hatch concluded that "Ultimately, this becomes a question of the credibility of the model." Morganthaler (1961) stated that "Simulation is still evolving, and the basic question of validity of results must be further resolved theoretically." Naylor, Balintfy, Burdick, and Chu (1966) maintained that "...the problem of verifying simulation models remains today perhaps the most elusive of all the unresolved problems associated with computer simulation techniques" and Sission (1969) concluded, "Thus, with a new simulation model about all that can he hoped for is a test of reasonableness and an act of faith." These types of thinking may be the reason that not one of the models in the DoD Catalog of Logistics Models (Air Force Institute of Technology, 1980) is reported to be validated.

Mayberry (1971) defined a valid model as one in which there is an earnest search for, and failure to find, a disqualifying defect. Mayberry listed six disqualifying defects:

(1) Symmetry--If two entities play the same role in the real world, they should play the same role in the model

(2) Continuity--If the real world is continuous, the model's output should be continuous

(3) Indifference to trivial aggregation--If two model parts are integrated, the output should be the same as for the separate representations

(4) Correct behavior in the limit--If the model's output at its limits is not credible, the intermediate points may also be suspect

(5) Correct direction of change--If a change in a real world independent variable causes a change in a real world dependent variable an acceptable model should reflect this change

(6) Physical dimension--If results changes are strictly dependent in the units of measurement employed, the model is suspect.

Hatch (1971) suggested a number of steps to be implemented during the model development to assure model validity. These included: (1) adequacy of concepts, (2) assurance that model agrees with design specifications, (3) test of model's assumptions, (4) verification of the model's results against predetermined results, and (5) comparison between model output and a real world process.

With the above backdrop in mind, we contend that model validation is feasible and that the Campbell and Fiske (1959) procedures for assessing convergent and discriminant validity through a multitrait-multimethod analysis represents the most appropriate method for validation of computer simulation models. When the traditional approaches to validation (i.e., content, construct, concurrent, predictive validity) which are prescribed for assessing the validity of tests, are applied as criteria for evaluating digital simulation models, two problems immediately became apparent. First, since models, unlike tests, contain a large number of constructs and are content diversified, it is not possible to make definitive statements in this regard. Individual models will vary, within themselves, in the degree of content and construct validity they possess. Similarly, if one undertakes the assessment of the predictive validity or of the concurrent validity of a model, the result will depend on which one or several of the output measures he chooses to investigate. Moreover, the magnitude of the required correlation for "acceptable" validity will vary with the proposed use of the output. The procedure described by Campbell and Fiske provides the solution to these procedural and interpretive problems.

Assume that a behavioral simulation model will make the following predictions about performance: crew competence, percentage of essential tasks completed, and performance adequacy. Assume further that independent outside criteria are available for each of these output measures. Table 3-2 shows the application of the Campbell-Fiske method to this validational problem. The cell entries in the table are correlation coefficients, and criterion A and criterion B represent independent estimates of the three output measures of interest.

Convergent validation implies a confirmation by independent measurement procedures; in this case, the predictions generated by the model are confirmed by both criterion A and criterion B. The demonstration of discriminant validity along with the existence of convergent validity is required for the establishment of construct validity. Convergent validity is demonstrated if the correlations in the validity diagonals (those entries circled in Table 3-2) are sufficiently larger than zero and sufficiently large to encourage further examination. Evidence for discriminant validity is threefold. First, the correlations in the validity diagonal should be higher than those in the heteroparameter-heteromethod triangles, which are in solid lines, and in which neither parameter nor criterion method are in common. Second, the values in the validity diagonal should be higher than those correlations between that parameter and other parameters with a common method of rating, i.e., the values in the validity diagonal should be higher than the values in the heteroparameter-monomethod triangles (which are in dashed lines in Table 3-2). Third, the pattern of trait interrelationships should be the same within and between outside criteria. In Table 3-2, the same pattern of trait relationships is shown in all the heteroparameter triangles of both the monomethod blocks and the heteromethod blocks. The above four comparisons can be conducted through an analysis of variance procedure described by Kavanagh et al. (1971).

Generality

The generality issue revolves around the question "Should the model apply only to one, specific system task, situation, or event, or should it apply to a class of these types of systems tasks, situations, or events?" This question needs answering early in the model development cycle and the answer will impact the cost of model development, the development time, and the predictive validity of the ultimate model.

Models built to represent a specific (often unique) situation are generally easier to conceptualize, structure, and develop. Accordingly, they are less costly to develop and the time required for their development is less than for a more general representation. However, the applicability of such models to other, even similar, situations will be highly limited. Accordingly, the cost of "ownership" for a highly specific model is probably allocable to the initial use.

On the other hand, while more general models are more costly in terms of developmental cost, such models are apt to be used regularly by a greater number of users. For example, the Siegel-Wolf (1969) model, initially developed by 1960 remains in use today. For such models, the cost of development, maintenance, and support can be amortized over a number of uses and users and the total cost of building one general model is almost certainly less than the cost of building several more specific models.

However, there is probably a trade off between generality and validity. As generality increases, validity probably decreases. Accordingly, in this problem area, as in several of those discussed previously, the modelist must come to an early decision. Failure to do so, may result in a disjointed model with different levels of generality included in each subroutine. Quite obviously, the output of a model can be no more general than the generality of its least general subroutine.

Table 3-2

Sample Matrix for Convergent-Discriminant Validity Analyses

		Predictions: Competence	Predictions: % Tasks Completed	Predictions: Performance	Criterion A: Competence	Criterion A: % Tasks Completed	Criterion A: Performance	Criterion B: Competence	Criterion B: % Tasks Completed	Criterion B: Performance
Predictions	Competence	(.89)								
	% Tasks Completed	.51	(.89)							
	Performance	.38	.37	(.76)						
Criterion A	Competence	.57	.22	.11	(.93)					
	% Tasks Completed	.23	.57	.12	.68	(.94)				
	Performance	.11	.11	.46	.59	.58	(.84)			
Criterion B	Competence	.56	.22	.11	.67	.42	.33	(.94)		
	% Tasks Completed	.23	.58	.12	.43	.66	.34	.67	(.92)	
	Performance	.11	.11	.45	.34	.32	.58	.58	.60	(.95)

User Interface

If a simulation model is to be used, the user must be able to interact easily with the model. The user's interaction with the model will take place in one of two forms. The user will need to enter into the model variable information which describes the conditions of the simulation or set of simulations which he wishes performed. For example, the NETMAN model requires such data as: operator proficiency, operator level of aspiration, task analytic data, number of messages arriving each hour, and number of characters per message. The second user interface, discussed in the subsequent section of this report, occurs when the user receives and must interpret the output of the model.

At the input end, several types of data entry are possible, including punched card, magnetic tape, or terminal. The most preferred data entry system is the one which is easiest for the computer naive individual to employ. Input through a terminal seems to meet this condition best. Of course, this implies the availability of a terminal to the user and a convenient form of data entry. If the terminal's displays have been designed for user convenience, the user of the terminal avoids a key punching step and the associated need to be acquainted with key punch methods and card formats. Of course, card (or tape) input can be provided as a back up mode or for use when an interactive terminal is not available.

The keys to user convenience are clear and understandable terminal displays, full use of cueing and menuing techniques, clear error statements which lead the user to the appropriate actions, the capability for local hard copy, and minimization of the required amount of user supplied information. A well designed, thorough, and tested user manual is also a necessity. The user manual is not a programmer's manual but rather a nontechnically oriented description of the simulation, what it can and can not do, how to interpret the results and how to log on, enter data, correct mistakes, and run the simulation. One instructional presentation technique, employed by Applied Psychological Services in the development of the PERFECT continuous operations simulation (Siegel et al., 1980) for a print-only terminal is shown in Figure 3-2. In the Figure 3-2 example, (which is the first page of a set) the user first enters the command OLD PERFECT and presses the R (return) key on the terminal. The computer system responds with an *(asterisk) and the operator presses the F, R, N, and return keys. The computer responds with the current time and date and the question PRINT OFF LINE DATA AND INTERMEDIATE ARRAYS - Y or N. The operator responds Y (yes) or N (no). This step-by-step procedure is followed until the simulation is completed. The operator can keep such a procedural guide on his desk and run the simulation with little additional indoctrination.

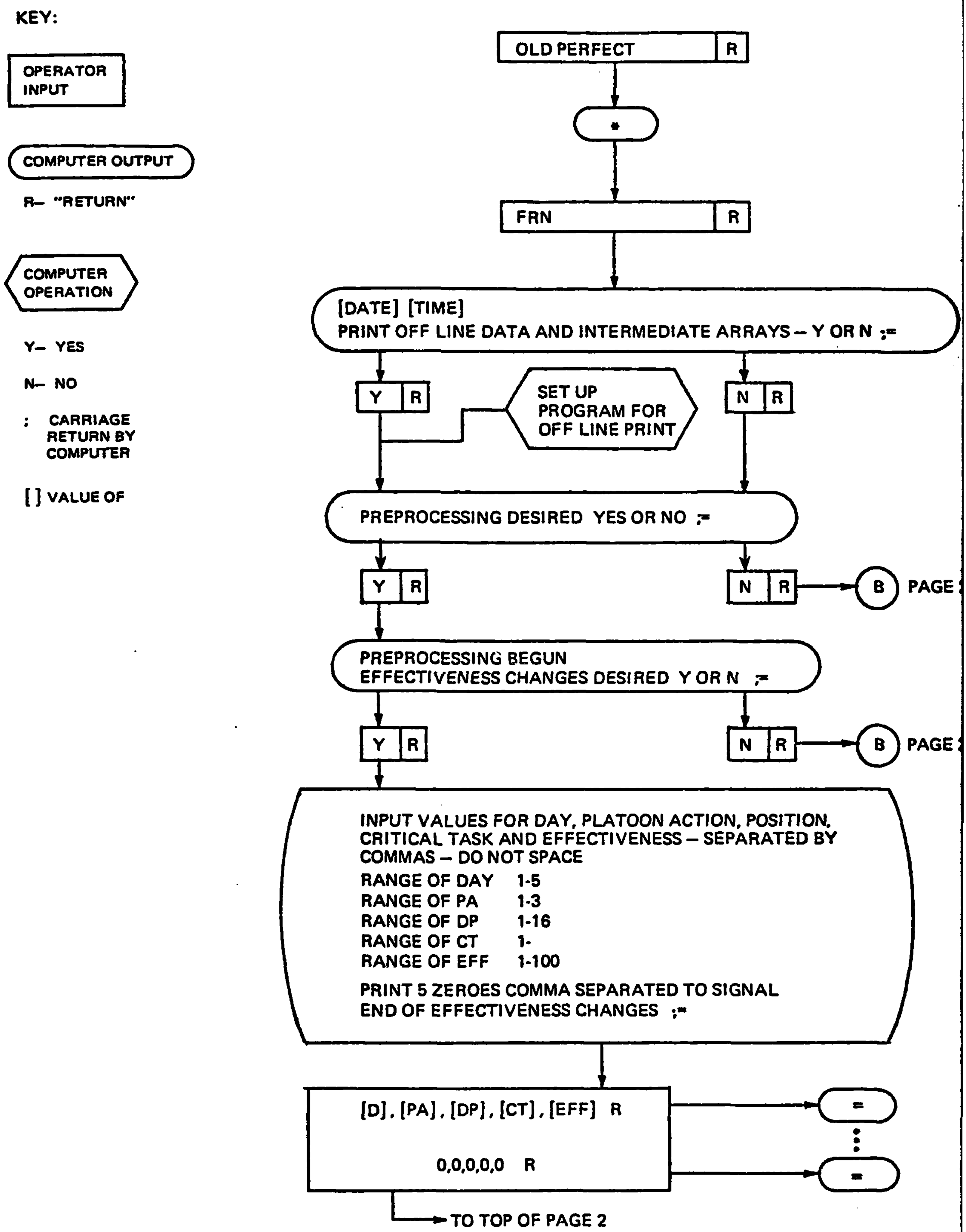

FIGURE 3-2. PARTIAL SET OF OPERATING INSTRUCTIONS FOR PERFECT SIMULATION.

Output from Simulation

The output of a model and the interpretation of the output represents the second aspect of the operator-model interface. Here, it is necessary to provide the user with the decision oriented information he requires at his desired level of detail and in a form which he can use.

Unfortunately, it is often not possible to know the answers to these questions in advance. And, different users will possess different requirements. Accordingly, it is best to provide the user with the option to select on the basis of user input those output tabulations he requires. With options specified at run time, the user has complete flexibility on the level of detail to review. To provide full flexibility, a minimum of three output detail levels or levels of data reduction of tabular results should be provided:

Increasing Level of Data Reduction

Full detail-- full detail of simulation results for each event, time segment, operator, etc. simulated. This is particularly useful in checkout of new input data sequences or for studying specific situations in detail.

Intermediate--consolidation of events or time segments by hour, day, or some convenient scaling. This level is valuable for archives, for allowing ad hoc summaries, and for review of general results.

Summary-- major output summarized across events, time segments, days, operators and the like.

On the output recordings at each level, appropriate listings of initial conditions and parameters which generated the output should be presented, if only for reference purposes.

In addition, it is useful and desirable to provide the output of major variables in graphic form or to accent high and low points in the simulated performance. Table 3-3 shows some types of output which should be utilized at each of the three levels of simulation.

Table 3-3

Types of Model Output Potentially Available

Tabular Lists

- Initial values and conditions
- Status of variables
- Identification information
- Present conditions
- Operator/computer error conditions

Summary Lists

- Average values
- Cumulative values
- Ranges of values
- Final (end of period) values
- Frequency distributions and probability of events
- Totals

Plots/Graphics

- Variable(s) vs. time
- Variable(s) vs. variable or parameter
- Frequency distrubutions, bar charts
- Pictoral presentations
- Maps, layouts, pie diagrams
- Block diagrams

User Acceptance

The problem of user acceptance of a behavioral simulation model and its data is a major concern to the behavioral simulation developer. On the one hand, there are users who will say that if the computer calculated a result, the result must be correct. On the other hand, there are those with an "I'm from Missouri" attitude who will believe that behavior is too complex to be represented by any computer model. Either extreme represents an untenable attitude.

How can one assure user acceptance? A number of the features which should be built into a model in order to assure its utility and acceptability were discussed in the preceding sections. These included: (1) minimum input data requirements, (2) availability and pertinence of required input data, (3) appropriately documented and structured programming in a common language, (4) transportability, (5) proper validation, (6) appropriate level of generality, (7) output which provides results at the appropriate level of detail, and (8) a convenient user interface.

At a different level of analysis, some users will want to know the details of the steps involved in the development of the model. Is this an *ad hoc* development or does it represent the outcome of a systematic set of analyses and tests? While one can not prespecify the steps to take in the development of any specific model, the generalized sequence of events involved in developing a behavioral model which is to be used to assist the decision making process is shown in Figure 3-3 (Siegel & Madden, 1979).

The figure is read from the bottom to top with the considerations involved in each stage entering from the left of each box and the results of each stage exiting to the right. The number(s) above each Figure 3-3 box represent criteria which may be applied after each developmental stage. These criteria are defined in Table 3-4. The rounded boxes associated with each rectangular, stage box represent descriptors which may be applied as the criteria at the successive stages are met. Accordingly, a model may be successively called "suitable," "testable," "reasonable," "valid," "effective," and "useful."

Cost/Effectiveness

The cost of model development and the cost of model application represent two distinct but interrelated model development considerations. Both depend heavily on the type of model. Table 3-5 presents the several generic types of Army models (TRADOC Pam 71-12, 1979). It includes five types, from the most abstract (analytical model) to the reality of actual combat.

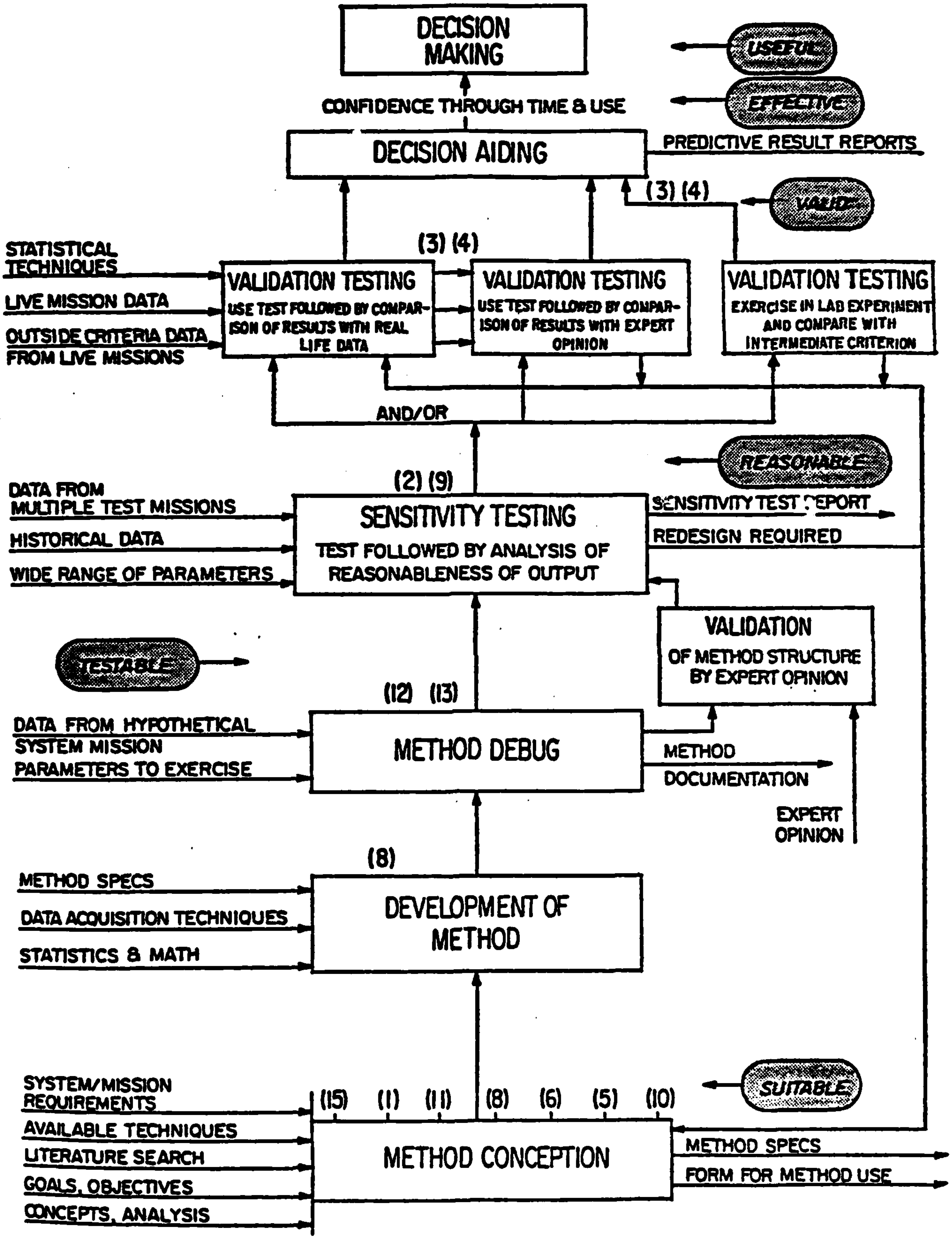

Figure 3-3. Sequence of model development.

Table 3-4

Criteria for Evaluating a Model During Its Development

	Criterion	Definition
1.	Internal consistency	Extent to which the constructs are marked by coherence and similarity of treatment
2.	Indifference to trivial aggregation	Potential to avoid major changes in output when input groupings or conditions undergo insignificant fluctuations.
3.	Correct prediction in the extreme (predictive or empirical validity)	Extent of agreement (correctness of predictions) with actual performance at very high/low values of conditions
4.	Correct prediction in mid range (predictive or empirical validity)	Like above for middle range values of conditions
5.	Construct validity	Theoretical adequacy of the constructs
6.	Content (variable/parameter) validity (fidelity)	Extent to which the variables/parameters match real life conditions
7.	Realism or "face validity"	Extent to which selected content matches each attribute included
8.	Richness of output	Number and type of output variables and forms of presentation
9.	Ease of use	Extent to which an analyst can readily prepare data for, apply, and extract understandable results
10.	Cost of development	Cost of effort to conceive, develop, test, document, and support
11.	Transportability-generality	Extent of applicability to different systems, missions, and configurations
12.	Cost of use	Value of all effort involving use of model including input, data processing, and analysis of results
13.	Internal validity (reliability)	Extent to which outputs are repeatable when inputs are unchanged
14.	Event or time series validity	Extent to which aid predicts event sequences

Table 3-5

Cost Aspects by Type of Model

Realism Increase	Model Type	Primary Model Aspects: Resolution (Detail)	Primary Model Aspects: Responsiveness	Primary Model Aspects: Realism	Typical Cost to Develop and Utilize: Personnel Time	Typical Cost to Develop and Utilize: Computer Time	Typical Cost to Develop and Utilize: Other Cost Elements	Estimated General Cost Characteristic (Scale 1-10)
↓	1. Analytical Models							
	Large Force Small Force	Low High	High	Low	Man Hours - Man Months	Little or None	NA	1-3
	2. Deterministic	Fairly High	Good	Somewhat Lacking	Man Weeks - Man Months	Small to Moderate	NA	3-5
	3. Probabilistic	High	Low	High	Man Weeks - Man Months	Moderate to Large	NA	4-7
	4. Manual War Games	High	Very Low	High	Man Weeks - Man Years	None	NA	5-8
	5. Field Tests and Experiments	High	Low	Very High	Man Months - Man Years	None	Test Sites	7-10
	-- Actual Combat	High	Very Low	Top Score	Man Hours - Man Months	None	Forces, Equipment	NA

Three primary aspects of a model (resolution capability, responsiveness, and realism), as rated by the authors of the TRADOC handbook, are shown in Table 3-5 along with a relative cost scaling. (Note that two of the five model types are concerned with computer simulation). The definition of each model type is:

Analytical Model	-	often prepared by an analyst at his desk or with a small amount of computer support
Deterministic Model	-	often a series of analytic models, constantly updated; an "expected value" model (involves computer)
Probabalistic Model	-	a "Monte Carlo" model which simulates a series of conditions (uses computer)
Manual Model	-	a game played by knowledgeable personnel most useful for evaluation of large forces
Field Tests and Experiments	-	live prearranged engagements; realistic yet simulated.

To place the five model types into perspective, consider the cost elements, i.e., the tasks and resources involved in model design, implementation, maintenance, and utilization. Table 3-6 itemizes these primary tasks and assigns a Y (yes) or N (no) to each task.

The TRADOC handbook also states that, at least for combat simulation, the probabalistic model (the type of greatest pertinence to this report) should be the basic study model. The deterministic model is a valuable supplement but should not be used as the principal model to support a study if a probabalistic model is available. Likewise, analytical models, which give a single answer and not a distribution, can be misleading; but, they too serve an important function if used to supplement models of higher resolution and are preferable if no other suitable models are available. The manual model (e.g., war games) are of greatest value and the primary tool for simulating large forces but may be partially replaced by computer simulations for levels below the battalion. The principal value of field tests and experiments is to serve as a source of data for input to other model types.

In connection with the development of the NETMAN model, computer running costs were analyzed (Siegel, Leahy, & Wolf, 1979). The cost of computer time for model development was only a small portion of the total

Table 3-6

Design Tasks for Each TRADOC Type of Model

Tasks	Analytical Models	Deterministic Computerized Models (Simpler)	Probabalistic Computerized Models (More Complex)	Manual Models	Field Tests and Experiments	Actual Combat
Model Design -- Once						
Define/conceive model	Y	Y	Y	Y	Y	Y
Determine information and data requirements	low	Y	Y	Y	Y	N
Collect information and data for model	Y	Y	Y	Y	Y	N
Define parameter/variable types	Y	Y	Y	N	N	N
Define inputs/outputs	Y	Y	Y	Y	Y	N
Define functional relationships	Y	Y	Y	N	N	N
Validate model concepts	Y	Y	Y	Y	N	
Model Implementation -- Once						
Develop model flow charts	N	Y	Y	N	N	N
Select computer language	N	Y	Y	N	N	N
Prepare programming specs	N	Y	Y	N	N	N
Program, code, and test model	N	Y	Y	N	N	N
Perform model sensitivity test	Y	Y	Y	Y	N	N
Perform model validation test	Y	Y	Y	Y	N	N
Document the model	Y	Y	Y	Y	Y	Y
Model Maintenance -- Continuing						
Enhance with new features	--	Y	Y	N	N	N
Model Utilization -- Upon Each Need						
Data collection/parameter selection	Y	Y	Y	Y	Y	N
Execute computer runs	N	Y*	Y**	N	N	N
Make calculations	Y	N	N	N	N	N
Analyze, illustrate, evalutate results	Y	Y	Y	Y	Y	Y
Draw conclusions, make recommendations	Y	Y	Y	Y	Y	Y

* Rapid   ** Slower

development cost. This is considered typical. Thus, in the model development phase, cost of personnel resources usually far exceeds computer costs. In model application (i.e., utilization), computer use costs are dependent on time of day, extent of CPU and memory required, terminal vs. batch operations, billing policies, and the like. Primarily costs are dependent on the number of runs and run combinations selected. However, the unit cost for a computer run of a well programmed model is also quite modest. Thus, combining this information, we find that the model types which cost less traditionally yield less value and that multiple model types may often be called for an analysis of a specific situation.

At the present state-of-the-art for modeling, the decision as to which type or types of models to develop and maintain on a cost/utility or cost/effectiveness basis must still be made on a case-by-case basis. Often personal safety, test site availability, types of personnel skills (analytical, programming) and computer equipment available as well as time schedule requirements (rather than an analysis of which type of model is best solely on the basis of the cost and effectiveness) may determine the type of model selected for a given application.

Some of the relationships involved in computer model costing are:

<u>Life Cycle Cost</u>

$$LCC = MDC + MTC + MMC + \sum_n MUC_n$$

<u>Model Development Cost</u>

$$MDC = MCC + MPC + MDAC + MDDC$$

<u>Model Test Cost</u>

$$MTC = MSTC + MVTC$$

<u>Model Maintenance Cost</u>

$$MMC = MEC + MECC + MMDC$$

<u>Model Utilization Cost</u>

$$MUC = RSC + \sum_j (CMC_j \cdot CTR_j)_u$$

<u>Model Conceptualization Cost</u>

$$MCC = (\sum_i DLH_i \cdot DLR_i)_c + MTO_c$$

<u>Model Programming Cost</u>

$$MPC = (\sum_i PLH_i \cdot PLR_i)_p + \sum_j CMC_j \cdot CTR_j + MTO_p$$

<u>Model Sensitivity Test Cost</u>

$$MSTC = \sum_i (TLH_i \cdot DLR_i)_s + (CMC_j \cdot CTR_j)_s + MTO_s$$

Model Validation Test Cost

$$MVTC = \sum_i (TLH_i \cdot DLR_i)_v + (CMC_j \cdot CTR_j)_s + MTO_s$$

where:

MDC	= Model Development Cost
MTC	= Model Test Cost
MMC	= Model Maintenance Costs
n	= Number of Model Applications or Uses
MUC_n	= Cost of Model Use
MCC	= Model Conceptualization (problem definition) Cost
MPC	= Model Programming Cost
MDAC	= Model Data Acquisition Cost
MDDC	= Model Design Documentation Reporting Cost
MSTC	= Model Sensitivity Test Cost
MVTC	= Model Validation Test Cost
MEC	= Model Enhancement Cost
MECC	= Model Error Correction Cost
MMDC	= Model Maintenance Documentation Cost
C	= Conceptualization Phase
P	= Programming Phase
S	= Sensivity Test Phase
V	= Validation Test Phase
U	= Utilization Phase
i	= Personnel Types Involved
DLH	= Design Labor Hours
DLR	= Design Labor Rate
MTO	= Material, Travel, and Other Costs
PLH	= Programming Labor Hours
PLR	= Programming Labor Rate
CMC_j	= Cost of Computer Related Elements$_j$, Per Unit Time (computer, memory, line costs)
j	= Types of Computer Related Costs
CTR_j	= Time Required of Computer Related Elements$_j$
TLH	= Test Labor Hours
TLR	= Test Labor Rates
RSC	= Run Setup Cost

Other Pervasive Issues

The fundamental ingredients for any behavioral simulation which purports to be at all complete, were presented earlier. However, a number of more vexing issues remain to be discussed. These issues represent areas in which there is possibly less agreement among behavioral modelists and which, accordingly, must be given greater critical consideration during model development.

Type of Model as a Function of Human Characteristics to be Simulated

Earlier the distinction was made between functional and psychological representations within a model. Psychological models were depicted as representation through higher order constructs which impact the model's throughput or events simulated. Functional models were described as more or less direct representations of the events, physical attributes, or throughput. The contrast between the two approaches may be visualized as shown in Figure 3-4. The question to be answered concerns the appropriateness of the psychological <u>or</u> functional models for representing human behavior. (Here, we note that in actual practice the mixed model will most often be constructed. Nonetheless, the dichotomy is useful at least during the early stages of model planning.)

The variables built into behavioral models can be categorized as cognitive, conative, perceptual, emotional, and motor. Because psychological models depend on the availability of behavioral theory, it is necessary to evaluate the status of the theory available in each of these categories. Specifically, for model development purposes, four questions must be answered about each behavioral category:

1. What is the adequacy of behavioral theory?
2. If competing theories are available, is it possible to make a choice among them?
3. Can a selected theory be represented through computer simulation; i.e., is the selected theory amenable to mathematical or functional representation?
4. Are the necessary input data available or obtainable at a sufficient level of reliability/validity?

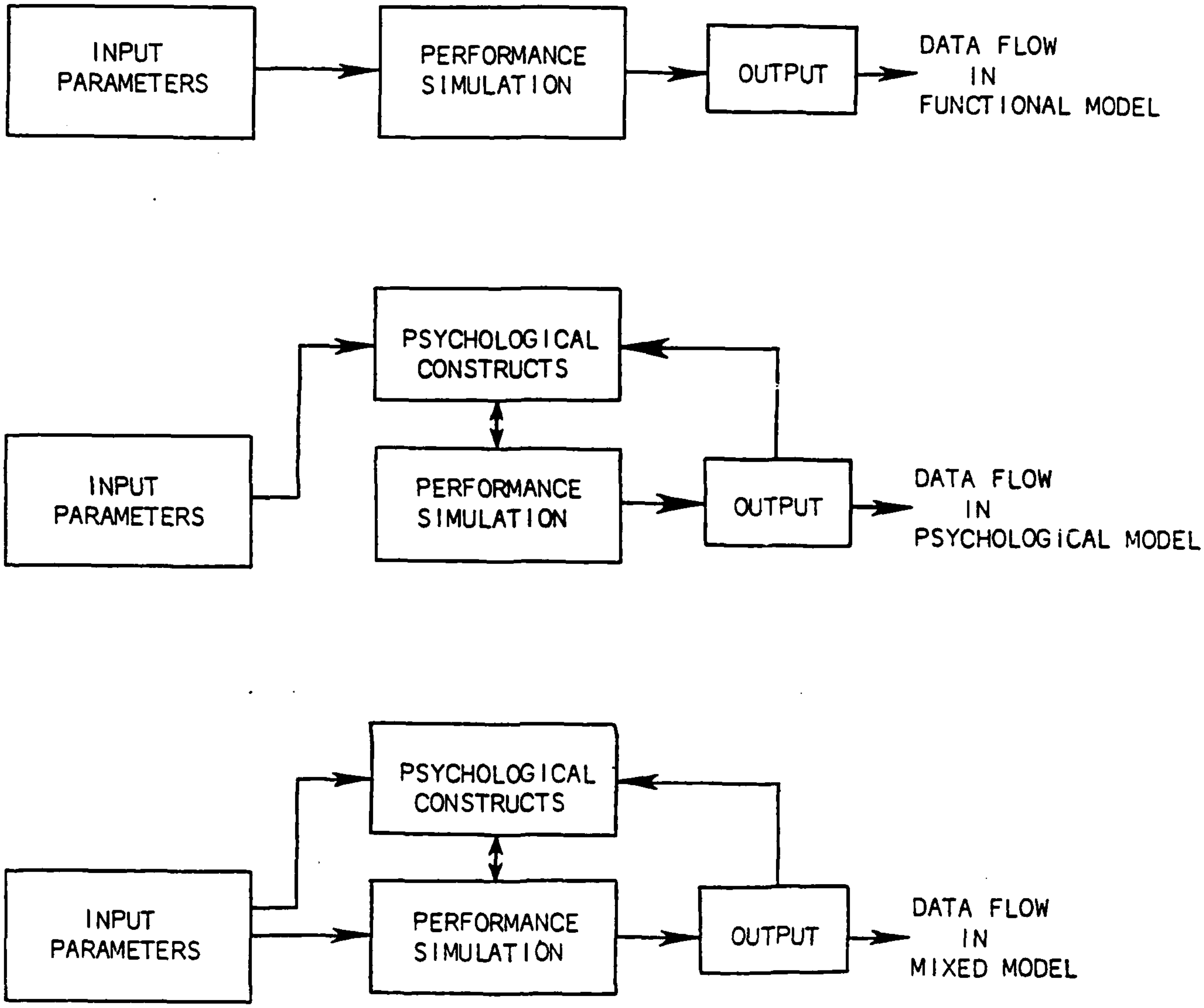

FIGURE 3-4. DATA FLOW IN FUNCTIONAL, PSYCHOLOGICAL, AND MIXED MODELS.

Table 3-7 presents an evaluation of each behavioral category against each of the critical questions. Table 3-7 suggests that the perceptual, motor, and cognitive categories are presently most amenable to psychological simulation. The conative and emotional categories are judged to have considerably less well developed theory and data availability. They are therefore judged to be less amenable to representation in current behavioral computer simulation.

Individual Difference Representation

One inherent advantage of behavioral simulation rests in its ability to represent within and between individual variations as part of the simulation. (Within individual variations refer to the fact that on two different occasions individuals seldom perform the same act in precisely the same manner or time. Between individual differences refer to ability differences among persons. Some people learn faster than others; some work faster than others, etc.)

The within individual variation problem is generally managed through the introduction of distributions, rather than points, into the simulation process. For example, rather than enter as input a given time duration (X) to perform a given event, a mean ($\bar{X}$) and a standard deviation (σ) are entered or calculated. During the simulation of the event, a random number is drawn from a preselected distribution. (When the normal distribution is used, this random number is called a random deviate.) The actual event performance time to be employed in a simulation may then be determined on the basis of $\bar{X}$, σ and the random deviate. The result is a stochastically selected performance time for the simulated event. Obviously, the random number distribution need not be normal. Most frequently, uniform normal, Poisson, and rectangular distributions are employed. Most computer systems offer callable routines to generate random numbers selected from these distributions. Because of the random number generation process, a large number of simulations may be needed in order to obtain a stable result when such a scheme is employed.

In general, the problem of differences between individuals is handled through input which serves to "adjust" the simulation in accordance with the type of person to be simulated. Several examples of this type of manipulation follow:

Table 3-7

Evaluation of Behavioral Categories Against Four Critical Questions

	Behavioral Category				
	Cognitive	Conative	Perceptual	Emotional	Motor
Theory Adequacy	+	0	+	0	+
Theory Choice	+	0	+	+	+
Computer Simulation Amenability	+	0	+	0	+
Input Data Availability	0	-	+	-	+

Key: + = relatively high
0 = intermediate
- = relatively low

- In the Siegel-Wolf (1969) model, an input value is entered to represent the proficiency of the persons simulated. This value is scaled from 0.5 to 1.5 to represent various levels of proficiency. The input values act multiplicatively on response time and success probability distributions with the end result that more proficient simulated operators "work faster" and "make fewer errors." Separate computer runs are completed. Each of these is completed with a different proficiency value. Comparison of the results from the separate runs allows a comparison of the effects of between individual differences in proficiency on task success.

- In a large group simulation model, (Siegel, Wolf, Barick, & Miehle, 1964), three types of "orientation" (towards self, towards unit, towards mission success) are entered for each person simulated and for each task. To simulate the effects of differences between individuals in "motivation" on performance, the simulation compares the orientation mix of the individual(s) simulated with the orientation of the task and performance effectiveness and is adjusted in accordance with the results of this comparison. The end result is that performance effectiveness is superior for persons whose orientation matches the orientations of the task and is inferior where there is a mismatch between the orientation of the task and that of the individual(s) performing the task.

- In an intermediate size crew model (Siegel, Wolf, & Cosentino, 1971), the effects of between leader differences in performance expectation on performance effectiveness are simulated. The leader's expectation value reflects the leader's expectation of performance effectiveness on the basis of the competency of the individual performing the task. To accomplish the simulation, the performance effectiveness (as calculated by the simulation) is compared with a leader's expectation value which is entered as an input parameter. Task performance effectiveness is then adjusted on the basis of the discrepancy. Comparison of the results of separate runs with varying input leadership expectation values permits the study of the effect of leaders expectation independent of other aspects.

- Several of these and other models contain an individual stress tolerance value to reflect individual differences in reaction to stress. The stress tolerance value serves to indicate an individual stress threshold. When situational stress reaches this threshold, performance effectiveness deteriorates. As a result of this implementation, individual differences in stress tolerance may be compared by means of the simulation.

Changes Over Time

Our ability to store and to retrieve data in high-speed digital computers, and to employ the retrieved values as the basis for subsequent calculations makes the simulation of changes over time quite feasible. Given an adequate data base, almost any time dependent effect can be built into a behavioral simulation model. However, the critical point lies in making judgments about the adequacy of the data base. The data base may have been derived from laboratory experiments which bear little relationship to the time dependent relationships in the model user's situation. For example, does "normal" fatigue data apply to behavior on the integrated battlefield?

Parameter Estimates

The inclusion in a model of a feature which allows user choice of parameter ranges for simulation is highly desirable because such a feature allows considerable flexibility in model use and enhances model utility. But, the more extensive the parameter choice, the more the following question is raised: Is adequate information available to the model developer so that he can provide a reasonable subset choice?

- Some types of parameter options can be selected for inclusion in a model with little concern for the question. For example, the parameter: "number of men in the crew" is a powerful one from the point of view of use of model output. Inclusion of the parameter in a model merely requires the selection of several integers over the range of potential interest. No research or laboratory experimentation is required in order to provide values for this input parameter.

- Other parameter selection options may be provided if a literature search shows the availability of experimental data or appropriate data banks. Alternately, if no data appear to be available, the cost of developing the data via tailored experimentation, calculation, or other techniques should be evaluated. It is poor policy to choose variables for modeling if (1) the user has no way to select input values or, (2) if he cannot relate these variables to real world conditions. However, no matter how extensive the extant data may be, it may not be possible to satisfy all purists on the matter of data adequacy.

- Another approach to parameter range estimation could be through application of the Delphi technique. Here, a series of persons experienced in the parametric aspects of interest are asked to quantify their experience under selected conditions.
- Parameter range selection is also possible through informal measurement. A quasi real life situation involving the specific parameter(s) of interest is devised and subjects are measured on performance in the situation. The results are used as a basis for parameter range estimation.

Human Variables

Simulations involving behavioral variables and small groups have been in use at least since the mid 1950s. Table 3-8 was prepared to identify some human behavioral oriented variables which are suitable for use in behavioral person-machine simulations. Which of these or others is to be utilized in a simulation model is a matter to be determined in each specific case and depends upon a variety of considerations including the following:

- size of group or crews to be simulated
- time increment and mission duration to be simulated
- environmental or other conditions to be simulated
- type of mission/system to be simulated
- level of generality planned for the model
- resources and capabilities available
- time available for model development/testing
- desired response time for model utilization

Situational Variables

The interaction of human performance characteristics (simulated by the human variables) with situational variables assumes importance when such variables may differentially affect human performance. The selection

Table 3-8

Examples of Possible Behavioral Variables

Information Processing

memory
analytic ability
inductive reasoning
deductive reasoning
comprehension
remote association
ability to see consequences
general intelligence
evaluative ability
rationality

Flexibility-Adaptability

creativity
ideational fluency
teamwork
enterprising orientation

Personal Traits

carelessness
practical values
investigativeness
need for autonomy
need for change
need for order
harm avoidance
impulsivity

Psychomotor Coordination

speed of arm movement
wrist or finger speed
reaction time
arm-hand steadiness
aiming
finger dexterity
manual dexterity
control precision (large movements with fine control)

Psychomotor Coordination (con't)

multilimb coordination
rate control
static strength
dynamic strength
explosive strength
trunk strength
extent strength
dynamic flexibility
body coordination
gross body equilibrium
stamina
running speed

Personnel Management and Interaction

self evaluation
evaluation of others
self confidence
social intra-extraversion
expressional fluency
restraint
ascendence
sociability
emotional stability
friendliness
personal relations
leadership style
orderliness
dedication to goals of installation
dedication to goals of USA
family ties
moral values
crime involvement
alcoholism
drug addiction
self control
cooperation
perceived social climate
personal power
persuasiveness
training

Table 3-8 (cont.)

Personal Characteristics	Group Characteristics
intellective ability	cohesiveness
training/proficiency	morale
	leadership
	communication

of situational variables for inclusion in a model is dependent on the character of the model planned and the subject matter of the system being simulated. Table 3-9 presents situational variables which have been incorporated into various behavioral models. Table 3-9, of course, is not complete. Situational variables may be as diverse and numerous as the types of systems for potential simulation.

The use of situational variables lends significant realism to a model. However, the model builder should remember that: (1) pseudo realism can be easily brought to an excess to the detriment of the model and all concerned, and (2) the true test of a model is its ability to assist in decision making and not the number of relational equations which give the appearance of reflecting the real world.

Table 3-9

Examples of Situational Variables

System Characteristics	Supply
queue length	frequency
safety level	rate of consumable use
distance between entities	amount of resupply
communications network	
procedures	**Opposing Force**
failure rate	number
repair time	type of weapons
redundancy level	weapon mix
time used, idle, inoperable	sensors
type	
Environment	**Management Actions**
heat	work day length
light	watch length
ventilation	personnel policy
terrain features	promotion policy
sea state	
air smoothness	

IV. CURRENT STATUS AND FUTURE TRENDS IN BEHAVIORAL MODELING

Current Trends and Status

The status of the stochastic computer simulation technology is such that this approach now represents a generally accepted tool for system effectiveness prediction. This holds whether economic, social, person-machine, or other systems are involved. Standard texts in industrial design (e.g., Forrester, 1961) recommend the use of the technique, as do current texts in human factors engineering (e.g., McCormick, 1964). For human involved systems, various agencies have come to rely more and more on the use of such models. Examples of the use of prior models by the military include sonar system and aircraft design in the Navy, advanced aircraft design in the Air Force, communications system investigation in the Army, and fire control system design in the Navy. All of these applications include circumstances in which the use of other types of predictive methods are untenable, uneconomical, or impossible.

Feiler made the following comment on simulation in manpower planning in 1971. It has since been followed by many others in dozens of areas and remains representative of current thought: "General purpose computer simulation has been demonstrated by many applications to Navy problems--to be a useful and efficient tool for manpower and personnel planning. It is competitive with special-purpose simulation for certain problem applications; it is uniquely suited to others."

Similarly, Smillie & Ayoub (1980) found that "computer simulation can indeed be used as a viable alternative to laboratory experimentation." Their study "exemplified the fact that the computer simulation provides the job performance aid designer and evaluator with a means by which he can assess and evaluate different job performance aid format combinations under varying conditions."

McLeod (1968) saw a very bright future for simulation in general, even at that relatively early date:

> However, no matter how I strain, I see nothing which might limit the current exponential increase in the influence of simulation on our way of life in years to come.

The use and acceptance of models, as he and others predicted, has in fact, come to pass. This trend has been followed for both behavioral model and for models in other fields.

This trend toward greater use of modeling will continue throughout at least the first half of the 1980s due to the following representative related technological trend developments whose impact has not yet been fully realized:

- exponential growth in the availability of computational power due to reduced hardware costs
- wide acceptance of and significant growth of educational processes leading to today's computer scientist. This is related to:
  - (1) the current acceptance of the computer field as a science rather than an art
  - (2) the development of many theoretical underpinnings of the field (e.g., structured programs, correctness proofs)
  - (3) the explosive growth of the number of trained personnel in analysis, and programming
- the impact of on-line program development and maintenance, as well as on-line conversational program runs
- the orders-of-magnitude reduction in the cost per bit of storage, the cost per bit per second of long-distance transmission and the basic cost of computation per unit arithmetic/logical operation
- the feasibi'ity of transmitting large volumes of data over long distances
- improved computer system reliability via redundancy, error correction, fault tolerant operating systems, and component count reductions
- the adoption of federal standards for programming languages, storage media, transmission interface protocols and the like
- the drastic reduction in the volume of space required by computing equipment coupled with corresponding reductions in power (operating) costs

Although the art of behavioral model development has advanced over the years and although behavioral modeling has seen increased application, a wide variety of concerns still remain open. As with any evolving area, there is often disagreement on methods, emphasis, and concepts. While the thrust of the present report supports and encourages the use of behavioral models, we are also aware that economists have devoted considerable effort to econometric simulations with limited successes. While such models are freely employed to predict the state of the economy, six months or even a year from now, experience tells us that they often fail to predict even what will, in fact, happen next month or even tomorrow.

Thus, not all simulation developments have met with uniform success. But, the fact that these and other forecasts (including several behavioral simulations) have not been wholly utilitarian has not and should not disuade or discourage users from seeking the best advice available. While the state-of-the-art in behavior modeling may be primitive, the initial behavior modeling successes and the improvements achieved in forecasting by other fields offer promise for better behavioral forecasts in the future.

Future Trends

In earlier sections, the following expected future trends in behavioral modeling were introduced and described:

- Increased development and use of models. Expansion in quantity and diversity of models is anticipated.
- Increased cost/effectiveness due to decreased computer equipment (time) [illegible] a component of total model cost. While the hardware/software cost ratio continues to decrease and level off, the cost or availability of computer equipment will decrease effectively to only a small percentage of total simulation costs.
- Increased availability of easy to use, general purpose programming languages as primary vehicles for simulation programs.
- Decreased diversity of models by category, solution technique, advance method, and by type. There seems to have been as many techniques applied as have been conceived. This is attributed to the newness of the field and the concepts. As time progresses, less diversity is projected with some model types proving their value in specific applications and becoming local favorites.

From a user's standpoint, the use of on-line computer terminals is another significant trend. In the future, it is anticipated that terminals for simulation control (initiation, changes, and output) will be used almost exclusively. The use of graphic (either black and white or color) terminals for displaying graphs, maps, functions, bar charts, and the like (as well as tables and text) will be common. Direct hard copy recording will also be a user option. Networking, to allow the use of large host computers, can also be anticipated.

The physical shrinkage of the computational equipment involved in simulation is anticipated to continue. It will be manifested in the following ways:

- Minicomputers, super minicomputers, and micro computers will proliferate. They will be further concatenated into a myriad of configurations via local and long distance networks, resulting in genuine distributed processing, and access to powerful capabilities with small investments.
- The resultant miniaturization will allow direct, physical integration of powerful computing elements into computer terminals, printers, and plotting devices in the same way that the microprocessor has already invaded the wristwatch. Thus, in the future, the computer per se will be an adjunct, allowing devices like a "smart plotter" (plotter with a built-in computer) or a "smart terminal" to perform simulations now reserved for independent large computers.

As the use of behavioral simulation continues to accelerate, and we become more and more accustomed to the artificial (simulated) slowing down of fast processes and speeding up slow processes, common sense regard for the reasonableness of each model's output will be necessary. As stated by Frosch:

> Considering the present and anticipated rate of sociocultural changes in our society, I believe these conceptual considerations of purpose, scope, degree of abstraction and time scaling are particularly important. Otherwise, we will continually find ourselves committing one of the sins of simulation, i.e., forgetting that situations are imaginary and pretending that all the data are real. This is one of the real dangers of using R&D simulations for operational purposes when they are in fact still very much in the development phase (1971).

Future Behavioral Modeling Research and Development in the Army

Given the emphasis on system models in the Army and the current status of behavioral modeling, what can be said about areas of future research and development emphasis for behavioral modeling in the Army? On the basis of the prior review, it seems that the Army needs relative to behavioral simulation modeling fall into at least five areas:

- Wider understanding of utility of and progress in behavioral simulation.
- Greater use of behavioral variables in general simulation models.
- More applicable and comprehensive data bases.
- Availability of general simulation modules.
- Compatibility with emerging mini/micro computer technology.

These needs are described in greater detail in subsequent sections. Where the phrases "near term," "mid term," and "long term" are used, the respective implications are: "about one year," "about 2 to 4 years," and "about 5 to 8 years."

Wider Understanding of Utility of and Progress in Behavioral Simulation

The failure of Army system modelists to include human behavioral variables within their system models suggests a lack of understanding on the part of these persons about the current status of human behavioral modeling and about the contribution that such models can make to the enhancement of the utility of current Army system models.

<table>
<tr><td colspan="2">N E E D

Full dissemination of information about status and power of behavioral modeling.</td></tr>
<tr><td>METHOD
A set of seminars, brochures, and training sessions is developed and presented to industrial and military developmental personnel relative to behavioral modeling.</td><td>TIME PHASE
Near term</td></tr>
<tr><td>PERSONNEL REQUIREMENTS
1.0 person year</td><td>END PRODUCTS
Broader understanding by planners of the role of behavioral modeling and increased use of behavioral modeling in Army system planning and evaluation.</td></tr>
</table>

Greater Use of Behavioral Variables in General Simulation Models

Those most frequently employed current Army system simulation models should be identified and analyzed to determine which behavioral variables seem most relevant to their purposes and content. For each frequently employed system simulation model, compatible behavioral simulation modules (including man-in-the-loop simulation) should be developed so as to allow integrated output which considers both the behavioral and the equipment variables.

<table>
<tr><td colspan="2" align="center">N E E D

Behavioral modules which interact with frequently employed Army system simulation models.</td></tr>
<tr><td align="center">METHOD</td><td align="center">TIME PHASE</td></tr>
<tr><td>The most frequently employed Army system simulation models are identified. These are analyzed to determine salient behavioral variables. Behavioral modules are developed to represent these variables.</td><td>Mid term</td></tr>
<tr><td align="center">PERSONNEL REQUIREMENTS</td><td align="center">END PRODUCTS</td></tr>
<tr><td>3.5 person years</td><td>Army system simulation models which interactively consider both equipment and behavioral variables.</td></tr>
</table>

More Applicable and Comprehensive Data Bases

No behavioral simulation model can produce useful output unless a relevant data base is available for providing the required input. Such a data base should be based on Army personnel and be periodically updated as new data become available. Model users cannot be expected to develop their own data bases and the most carefully developed model can be rendered useless if inappropriate data are employed in its implementation.

N E E D	
Data bases for all Army developed behavioral simulation models.	
METHOD	**TIME PHASE**
Variables within current Army behavioral simulation models are isolated. Variables within anticipated models are similarly derived. Required data for supporting such variables are developed from literature and from formal measurements.	Mid to long term
PERSONNEL REQUIREMENTS	**END PRODUCTS**
3.0 person years	Full data bases to support current and anticipated behavioral simulation models.

Availability of General Simulation Modules

It is possible to build a set of generic modules which can serve as "off-the-shelf" plug ins to system models. Examples of such generic modules are stress effects, group cohesiveness, and the effects of fatigue. Given the availability of such modules, system modelists could then call them in much the same way that various subroutines are currently called from system libraries. Behavioral models could then be easily incorporated by system modelists into their simulation models.

N E E D	
Behavioral simulation modules which can be employed in a "plug-in" manner for incorporation into system models.	
METHOD Required behavioral simulation modules are prioritized. The logic for such modules is developed and the modules are programmed. The availability of such modules is publicized and descriptive literature is made available.	**TIME PHASE** Mid to long term
PERSONNEL REQUIREMENTS 4.0 person years	**END PRODUCTS** A set of behavioral modules which can be employed in an off-the-shelf manner by developers of Army system simulation models.

Compatibility with Mini/Micro Computer Technology

As pointed out earlier, the mini/microcomputer technology will significantly impact disciplines which rely on high speed computations. It seems that an analysis of this impact should be completed relative to behavioral simulation models.

NEED	
Specifications and standards relative to behavioral modeling within the mini/microcomputer technology.	
METHOD	**TIME PHASE**
An analysis is completed to determine optimum methods for developing behavioral simulation models/modules within the mini/microcomputer technology.	Near term
PERSONNEL REQUIREMENTS	**END PRODUCTS**
.75 person years	A set of standards and specifications for behavioral simulation models/modules which are oriented towards user implementation on mini/microcomputers.

REFERENCES

Aiken, L.S., & Brown, D.R. A feature utilization analysis of the perception of pattern class structure. Perception and Psychophysics, 1971, 9, 279-283.

Air Force Institute of Technology. Aggregate pilot pipeline model. Model #335 in Department of Defense Catalog of Logistics Models. Ft. Lee, Va.: U.S. Army Logistics Management Center, 1980.

Arnoult, M.D. Prediction of perceptual responses from structured characteristics of the stimulus. Perceptual and Motor Skills, 1960, 11, 261-268.

Baron, S. & Levison, W.H. Display analysis with the optimal control model of the human operator. Human Factors, 1977, 19, 437-457.

Baxter, J., & Harrison, J.Y. A nonlinear model describing driver behavior on straight roads. Human Factors, 1979, 21, 87-97.

Blanchard, R.E. Survey of Navy user needs for human reliability models. Santa Monica: Behaviormetrics, 1972.

Boham, G.M., Shapiro, M.J., & Nozicka, G.J. A cognitive process model of foreign policy decision-making. Simulation & Games, 1976, 7, 123-152.

Bres, E.S. Shore activity manpower planning models: Development and application. In Department of Defense Catalog of Logistics Models. Ft. Lee, Va.: U.S. Army Logistics Management Center, 1980. (No. 332)

Bruns, R.A., Bittner, A.C., & Stevenson, R.C. Effects of target size, target contrast, viewing distance on dynamic televisual target detection and identification (TP-72-24), Point Magu, Calif.: Naval Missile Center, 1972.

Buling, J. Maintenance manpower planning. In A.I. Siegel (Ed.), Symposium on Computer Simulation as Related to Manpower and Personnel Planning. Washington, D.C.: Naval Personnel Research & Development Laboratory, 1971.

Burger, R.T. User's manual for LOGATAK II, a simulation model to analyze transportation activities, logistics network distribution and interdiction. In Department of Defense Catalog of Logistics Models. Ft. Lee, Va.: U.S. Army Logistics Management Center, 1980. (No. 112)

Burt, M.P., & Valrand, C.B. Development and validation of a land combat performance and cost analysis model. In Department of Defense Catalog of Logistics Models. Ft. Lee, Va.: U.S. Army Logistics Management Center, 1980. (No. 175)

Campbell, D.T., & Fiske, D.W. Convergent and discriminant validation by the multitrait-multimethod matrix. Psychological Bulletin, 1959, 56, 81-105.

Carter, R.C., & Cahill, M.C. Regression models of search time for color-coded information displays. Human Factors, 1979, 21, 293-302.

Ceriello, V.R., & Frantzreb, R.B. A human resource planning model. Human Factors, 1975, 17, 35-41.

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

Charnes, A., Cooper, W.W., & Niehouse, R.J. Studies in manpower planning. Washington, D.C.: Office of Manpower Management, 1972.

Coluccio, T., & Wasielewski, J. Electro-optical image enhancement (RADC-TR-70-35). Rome, N.Y.: Grifiss Air Force Base, 1970.

Combat developments staff officer's handbook (TRADOC Pam 71-12). Fort Monroe, Va.: Headquarters, U.S. Army Training and Doctrine Command, 30 November 1979.

DARCOM Material Systems Analysis Activity. Hellmates: A helicopter engagement computer simulation. In Department of Defense Catalog of Logistics Models. Ft. Lee, Va.: U.S. Army Logistics Management Center, 1980. (No. 193).

Davis, J.D., & Levine, M.W. A model for the control of ingestion. Psychological Review, 1977, 84, 379-412.

Department of Defense catalog of logistics models. Fort Lee, Va.: Defense Logistics Studies Information Exchange, U.S. Army Logistics Management Center, 1980.

DiSalvo, V., & Bochner, A.P. PROF: A simulation and analysis technique for capturing information-processing policies. Simulation & Games, 1973, 4, 279-387.

Deutsch, M. Field theory in social psychology. In G. Lindsey (Ed.), Handbook of Social Psychology. Cambridge, Mass.: Addison Wessley, 1954.

Drury, C.G. Integrating human factors models into statistical quality control. Human Factors, 1978, 20, 561-572.

Dutton, J.M., & Starbuck, W.H. Finding Charlie's run-time estimator. In J.M. Dutton & W.H. Starbuck (Eds.), Computer simulation of human behavior. New York: Wiley, 1971.

Einhorn, H.J., & Klunmimtz, D.N. Linear regression and process-tracing models of judgment. Psychological Review, 1979, 86, 465-485.

Emshaff, J.R., & Sisson, R.L. Design and use of computer simulation models. New York: MacMillan, 1970.

Feigl, H. Readings in philosophical analysis. New York: Appleton-Century-Crofts, 1949.

Feiller, A.M. Tradeoffs among simulation approaches. In A.I. Siegel (Ed.), Symposium on Computer Simulation as Related to Manpower and Personnel Planning. Washington, D.C.: Naval Personnel Research and Development Laboratory, 1971.

Forrester, J.W. Industrial dynamics. Cambridge, Mass.: MIT Press, 1961.

Friedman, M. Essays in predictive economics. Chicago: University of Chicago Press, 1953.

Frosch, R.A. Simulation technology and manpower planning. In A.I. Siegel (Ed.), Symposium on Computer Simulation as Related to Manpower and Personnel Planning. Washington, D.C.: Naval Personnel Research and Development Laboratory, 1971.

Goclowski, J. Digital avionics information system (DAIS): Training requirements analysis model. Vol. II - user's guide. In Department of Defense Catalog of Logistics Models. Ft. Lee, Va.: U.S. Army Logistics Management Center, 1980. (No. 377)

Hakes, H.H. Form discrimination and the invariance of form. In L. Uhr (Ed.) Pattern Recognition. New York: Wiley, 1966.

Harris, D.H. Development of a computer-based program for criminal intelligence analysis. Human Factors, 1978, 20, 47-56.

Hatch, R. An ounce of valid specification is worth a pound of cure. In A.I. Siegel (Ed.), Symposium on Computer Simulation as Related to Manpower and Personnel Planning. Washington, D.C.: Naval Personnel Research and Development Laboratory, 1971.

Haythorne, W.W. Information systems simulation and modeling. In Information system simulation and modeling techniques. First Congress on the Information System Sciences, Report ESD-TDR-63-474-7. Bedford: Electronic Systems Division, 1963.

Inukai, Y., Saito, S., & Mishima, I. A vector model analysis of individual differences in sensory measurement of surface roughness. Human Factors, 1980, 22, 25-36.

Johnson, P.S. Computer-assisted military retirement information system: A proposed model. In Department of Defense Catalog of Logistics Models. Ft. Lee, Va.: U.S. Army Logistics Management Center, 1980. (No. 346)

Kavanagh, M.J., MacKinney, A.C., & Wolins, L. Issues in managerial performance: Multitrait-multimethod analyses of ratings. Psychological Bulletin, 1971, 75, 34-49.

Kelly, H.H., & Thibaut, J.W. Experimental studies of group probelm solving and process. In G. Lindsey (Ed.), Handbook of Social Psychology. Cambridge, Mass.: Addison-Wesley, 1954.

Kendall, M.G. Introduction to model building and its problems. In Mathematical Model Building in Economics and Industry. New York: Hofner, 1968.

Kornberg, A., Mishler, W., Smith, J., & Naylor T.H. Socializing political party officials: A simulation experiment. Simulation & Games, 1972, 3, 379-406.

Kramer, R.R. A simulation of the human shoulder. Aberdeen Proving Grounds, Md.: U.S. Army Human Engineering Laboratory, 1975.

Krech, D., & Crutchfield, R.S. Theory and problems of social psychology. New York: McGraw-Hill, 1948.

LaSala, K.P. Human reliability prediction system user's manual. In Department of Defense Catalog of Logistics Models. Ft. Lee, Va.: U.S. Army Logistics Management Center, 1980. (No. 179)

Levin, M. Displaying sociometric structures: An application of interactive computer graphics for instruction and analysis. Simulation & Games, 1976, 7, 295-310.

Levine, J.M., & Eldredge, D. Effects of ancillary information upon photointerpreter performance. Arlington, Va.: Army Research Institute for the Behavioral and Social Science, 1974.

Levy, G.W. Criteria for selection and application of models. In G.W. Levy (Ed.), Symposium on Applied Models for Man-Machine Performance. Columbus, Ohio: North American Rockwell, 1969.

Lewin, K. Time perspective and morale. In G. Watson (Ed.), Civilian Morale. Boston: Houghton, 1942.

Lozano, P.A. Computer simulation of KC-135 aircrew manning requirements. In Department of Defense Catalog of Logistics Models. Ft. Lee, Va.: U.S. Army Logistics Management Center, 1980. (No. 78)

Lucas, R.C., & Schechter, M. A recreational visitor travel simulation model as an aid to management planning. Simulation & Games, 1977, 8, 375-384.

Martin, F.F. Computer modeling and simulation. New York: Wiley, 1968.

Mayberry, J. Principles for assessment of simulation model validity. In A.I. Siegel (Ed.), Symposium on Computer Simulation as Related to Manpower and Personnel Planning. Washington, D.C.: Naval Personnel Research and Development Laboratory, 1971.

McCormick, E.J. Human factors engineering. New York: McGraw-Hill, 1964.

McLeod, S. Photointerpreter performance studies (RADC-TDR-64-326). Rome, N.Y.: Grifiss Air Force Base, 1964.

McLeod, J. Simulation, the modeling of ideas and systems with computers. New York: McGraw-Hill, 1968.

Miller, G.M., Heise, G.A., & Lichten, W. The intelligibility of speech as a function of the context of test materials. Journal of Experimental Psychology, 1951, 41, 329-345.

Morganthaler, G. The theory and application of simulation in operations research. In R.L. Ackoff (Ed.), Progress in Operations Research, Vol. I. New York: Wiley, 1961.

Munger, S.J., & Smith, R.W. An index of electronic equipment operability: Data store. Pittsburgh, Pa.: American Institute for Research, 1962.

Naylor, T.H., Balintfy, J.L., Burdick, D.S., & Chu, K. Computer techniques. New York: Wiley, 1966.

Niehaus, R.J., & Sholtz, D. A computer support system for large scale manpower planning. Washington, D.C.: Office of Civilian Manpower Management, Department of the Navy, 1974.

Newell, A., & Simon, H.A. Human problem solving. Englewood Cliffs, N.J.: Prentice-Hall, 1972.

Olson, S.H., Berlin, G.N., & Guiland, L.S. Computer modeling in a course on urban decision-making. Simulation & Games, 4, 440-453.

Olson, W.K. M60A3 improved suspension-task exchange model. In Department of Defense Catalog of Logistics Models. Ft. Lee, Va.: U.S. Army Logistics Management Center, 1980. (No. 247)

Orlov, R.D. AMSAA War game computer model. In Department of Defense Catalog of Logistics Models. Ft. Lee, Va.: U.S. Army Logistics Management Center, 1980. (No. 262)

Patterson, M.L. An arousal model of interpersonal intimacy. Psychological Review, 1976, 83, 235-245.

Penrod, S., & Hastie, R. Models of jury decision making: A critical review. Psychological Bulletin, 1979, 86, 462-492.

Rasmussen, R., & Stover, W. Simulation model for assessing WRSK capability at unit level. In Department of Defense Catalog of Logistics Models. Ft. Lee, Va.: U.S. Army Logistics Management Center, 1980. (No. 129)

Reed, S.K. Psychological processes in pattern recognition. New York: Academic Press, 1973.

Reesman, S. Dominoes: A computer simulation of cognitive processes. Simulation & Games, 1972, 3, 155-164.

Roberts, N. A computer system simulation of student performance in the elementary classroom. Simulation & Games, 1974, 5, 265-288.

Rubin, H.J. A note on PARADIGM: A simulation model of the competition of ideas in evolving groups. Simulation & Games, 1978, 9, 173-184.

Schecter, G. Tactical deterrence model: application to mine systems. In Department of Defense Catalog of Logistics Models. Ft. Lee, Va.: U.S. Army Logistics Management Center, 1980. (No. 195)

Schilling, W. Combat system survivability; Vol. II - overview of combat system survivability model, sections 1 and 2. Model #308 In Department of Defense Catalog of Logistics Models. Ft. Lee, Va.: U.S. Army Logistics Management Center, 1980.

Schwartz, M. A ship simulation model for manpower research. In A.I. Siegel (Ed.), Symposium on Computer Simulation as Related to Manpower and Personnel Planning. Washington, D.C.: Naval Personnel Research & Development Laboratory, 1971.

Seifert, D.J., Hann, R.L., & Chubb, G.P. Simulation using SAINT: A user-oriented instruction manual. In Department of Defense Catalog of Logistics Models. Ft. Lee, Va.: U.S. Army Logistics Management Center, 1980. (No. 171)

Siegel, A.I., Leahy, W.R., & Wolf, J.J. Application of computer simulation techniques in military exercise control system development: I. NETMAN model sensitivity test and validation. Wayne, Pa.: Applied Psychological Services, 1979.

Siegel, A.I., Leahy, W.R., & Wolf, J.J. A computer model for simulation of message processing in military exercise control and evaluation systems. Wayne, Pa.: Applied Psychological Services, 1977.

Siegel, A.I., & Madden, E.G. Decision aid program. Wayne, Pa.: Applied Psychological Services, 1979.

Siegel, A.I., & Wolf, J.J. Human effects aspects in simulating hostile attacks against nuclear facilities: I. Description of simulation model subroutines. Wayne, Pa.: Applied Psychological Services, 1978.

Siegel, A.I., & Wolf, J.J. Man-machine simulation models. New York: Wiley, 1969.

Siegel, A.I., Wolf, J.J., Barick, J.D., & Miehle, W. Digital simulation of submarine crew performance: I. Logic of a psychosocial "model" for digitally simulating crew performance. Wayne, Pa.: Applied Psychological Services, 1964.

Siegel, A.I., Wolf, J.J., & Cosentino. J. Digital simulation of the performance of intermediate size crews: Application and validation of a model for crew simulation. Wayne, Pa.: Applied Psychological Services, 1971.

Siegel, A.I., Wolf, J.J., Ozkaptan, H., & Shorn, A. Human performances in continuous operations: Users manual and description of a simulation model for evaluation of performance degradation. Wayne, Pa.: Applied Psychological Services, 1980.

Siegel, A.I., Wolf, J.J., & Williams, A.R. Computer simulation of human performance in electronic processed imagery systems. Wayne, Pa.: Applied Psychological Services, 1978.

Silverman, J. Decision making in enlisted force utilizing the ADSTAP simulation model. In A.I. Siegel (Ed.), Symposium on Computer Simulation as Related to Manpower and Personnel Planning. Washington, D.C.: Naval Personnel Research & Development Laboratory, 1971.

Silverman, J. Recruit input optimization. In Department of Defense Catalog of Logistics Models. Ft. Lee, Va.: U.S. Army Logistics Management Center, 1980. (No. 333)

Simon, H.A., & Newell, A. Human problem solving: The state of the theory in 1970. American Psychologist, 1971, 26, 145-159.

Sisson, R. Simulation: Uses. In J.S. Aronofsky (Ed.), Progress in Operations Research, Vol. II. New York: Wiley, 1969.

Smillie, R.J., & Ayoub, M. A. Job performance aids: Evaluation of design alternatives via network simulation. Ergonomics, 1980, 23, 319-339.

Staggs, D. ATAGAS: A flight test data reduction system for air-to-air gunnery assessment; Vol I. - User manual. In Department of Defense Catalog of Logistics Models. Ft. Lee, Va.: U.S. Army Logistics Management Center, 1980. (No. 230)

Starbuck, W.H. Testing case-descriptive models. In J.M. Dutton & W. H. Starbuck (Eds.), Computer Simulation of Human Behavior. New York: Wiley, 1971.

Steinberg, S. A computer model for evaluating the effects on fighting vehicle crewmembers of exposure to carbon monoxide emissions. Aberdeen Proving Grounds, Md.: U.S. Army Human Engineering Laboratory, 1980.

Torre, J.P., Jr. Prediction of target travel during missile time of flight: A computer simulation. In Department of Defense Catalog of Logistics Models. Ft. Lee, Va.: U.S. Army Logistics Management Center, 1980. (No. 185)

Trinnaman, J.E. Feasability of predicting reserve show rate at mobilization: A proposed model for mobilization manpower management. In Department of Defense Catalog of Logistics Models. Ft. Lee, Va.: U.S. Army Logistics Management Center, 1980. (No. 356)

Tulving, E., & Thomson, D.M. Encoding specificity and retrieval processes in spisodic memory. Psychological Review, 1973, 80, 352-373.

Turek, J.P. ALPOS: Avionics laboratory predictive operation and support cost model. Vol. I. In Department of Defense Catalog of Logistics Models. Ft. Lee, Va.: U.S. Army Logistics Management Center, 1980/ (No. 50)

U.S. Army Concepts Analysis Agency. TARTARUS IV N/COCO war gamer's manual. Model # 280 In Department of Defense Catalog of Logistics Models. Ft. Lee, Va.: U.S. Army Logistics Management Center, 1980.

Veldhuyzen, W., & Stassen, H.G. The internal model concept: an application to modeling human control of large ships. Human Factors, 1977, 19, 367-380.

Vertinsky, I., Buckingham, S.L., Walters, C.J., & Zoltman, G. Family planning computer simulation: The Costa Rica population control model. Simulation & Games, 1972, 3, 123-145.

Wanot, J. Parameters of electoral competitiveness. Simulation & Games, 1976, 7, 389-410.

Weintraub, A.C. VECTOR-2 system for simulation of theatre-level combat; program maintenance manual; Vol. I - Main simulation, binary formatter and postprocessor, Part I. Model #269 In Department of Defense Catalog of Logistics Models. Ft. Lee, Va.: U.S. Army Logistics Management Center, 1980.

Wilkinson, W.L. Exercise of the dynamic student flow model. In Department of Defense Catalog of Logistics Models. Ft. Lee, Va.: U.S. Army Logistics Management Center, 1980. (No. 387)

Wolford, G. Perturbation model for letter identification. Psychological Review, 1975, 82, 184-199.

Zusne, L. Visual perception of form. New York: Academic Press, 1970.