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NUREG/CR-3626, Vol. 1
ORNL/TM-9041/V1

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This Work Performed For
Nuclear Regulatory Commission
Under
DOE Interagency Agreement 40-550-75

OPERATED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161

Available from

GPO Sales Program
Division of Technical Information and Document Control
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

NUREG/CR-3626, Vol. 1
ORNL/TM-9041/V1
Distribution Category RX

Engineering Physics and Mathematics Division

MAINTENANCE PERSONNEL PERFORMANCE SIMULATION (MAPPS) MODEL: SUMMARY DESCRIPTION

Arthur I. Siegel*
William D. Bartter*
J. Jay Wolf*
Helmut E. Knee
Paul M. Haas

NRC Monitor:	Thomas G. Ryan Human Factors Branch Division of Facility Operations
Program Manager:	P. M. Haas Oak Ridge National Laboratory
Principal Investigator:	H. E. Knee Oak Ridge National Laboratory

Manuscript Completed: February 1984
Date Published: May 1984

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Under
DOE Interagency Agreement 40-550-75
NRC FIN No. B0461

Work Performed Under
ORNL Subcontract No. 62X-70527

*Applied Psychological Services, Inc.
Science Center
Wayne, PA 19087

Prepared by the
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831
operated by
Martin Marietta Energy Systems, Inc.
for the
U.S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-840R21400

FOREWORD

This report is the first of a two volume set that describes a human performance computer simulation model developed for the nuclear power plant maintenance context. The model, entitled *MA*intenance *P*ersonnel *P*erformance *S*imulation (MAPPS) is the result of a program undertaken by the Oak Ridge National Laboratory (ORNL) for the U. S. Nuclear Regulatory Commission (NRC), Office of Nuclear Regulatory Research. Development of MAPPS was carried out by Applied Psychological Services, Inc., under subcontract to ORNL.

The description of the model presented in this two volume report reflects the model's state prior to any calibrations identified through the sensitivity testing that it underwent. These minor calibrations will be incorporated into the model prior to evaluation/validation efforts that will be carried out during the remainder of FY-1984 and parts of FY-1985. Description of model calibrations, results of the evaluation/validation efforts, and suggested improvements to the model will be reported in a NUREG/CR report that will be issued subsequent to the completion of these efforts.

The formal transfer of the evaluated model to the NRC is currently scheduled for mid-year FY-1985 and will be accompanied by a MAPPS user's manual.

Subsequent efforts within this program include the planning and implementation of technology transfer of the model to potential users. This will include structured workshops, emphasizing proper application and correct interpretation of model output.

H. E. Knee, ORNL, Principal Investigator
P. M. Haas, ORNL, Program Manager

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ABSTRACT

A summary description is presented of the rationale for and the content and structure of the *MA*intenance *P*ersonnel *P*erformance *S*imulation (MAPPS) model. The MAPPS model is a generalized stochastic computer simulation model developed to simulate the performance of maintenance personnel in nuclear power plants. The MAPPS model considers work-place, maintenance technician, motivation, human factors, and task-oriented variables to yield predictive information about the effects of these variables on successful maintenance task performance. MAPPS provides human performance reliability information pertinent to probabilistic risk assessment, regulatory decisions, and maintenance personnel requirements. The model, which is drawn from a firm research analytic base, was examined for disqualifying defects from a number of viewpoints and its sensitivity was extensively tested. The MAPPS model is believed to be ready for initial and controlled applications which are in conformity with its purposes.

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ACKNOWLEDGEMENTS

We acknowledge the contributions of others to the work described herein. At Applied Psychological Services, Donald Mayberry, James Corliss, and Edward Madden programmed the *MA*intenance *P*ersonnel *P*erformance *S*imulation (MAPPS) stochastic computer model for the IBM 3033 system in the FORTRAN IV H (enhanced) programming language. Philip Federman performed the task analyses and prepared the required model input data for the sensitivity tests and Felix Kopstein developed the logic for the troubleshooting subroutine.

At the Nuclear Regulatory Commission, James Jenkins' early recognition of the need for research into nuclear power plant maintenance and the role of a simulation model in such research. James Pittman, Charles Overbey, Ellis Merschoff and most recently, Thomas Ryan continued to provide stimulation to our efforts and focus to our concepts and to serve as a sounding board for ideas. They assisted in coming to grips with almost all problems, reviewed various technical materials, helped in the organization and development of the work, and attended to numerous and time consuming administrative details.

We express our indebtedness to all of these persons without whose contributions the MAPPS model could not have been brought to its present status.

ARTHUR I. SIEGEL
WILLIAM D. BARTTER
J. JAY WOLF

Applied Psychological Services, Inc.
December 1983

Helmut E. Knee
Paul M. Haas
Oak Ridge National Laboratory
December 1983

1. INTRODUCTION AND SUMMARY

1.1 Purpose of Report

This two volume report presents the results of initial research on the feasibility of applying computer modeling techniques in analyzing and predicting the reliability of nuclear power plant maintenance personnel performance. The report is part of a larger Nuclear Regulatory Commission (NRC) research program whose immediate goal is to develop a technical support system for reliability evaluations at nuclear power plants, especially those employing probabilistic risk assessment (PRA) methodologies.

Volume 1 presents a summary description of the *MA*intenance *P*ersonnel *P*erformance *S*imulation (MAPPS) computer model, analytic methods and procedures employed in its development, its key features, and the results of sensitivity tests of the model.

Volume 2 (Ref. 1) presents detailed discussions of the logic and rationale of the MAPPS computer model, computer implementation and processing, and sensitivity test results.

MAPPS is currently undergoing calibration based on sensitivity test results and will subsequently undergo field testing to assess its utility (practicality, acceptability, usefulness) for supporting human reliability analysis (HRA) segments of PRAs.

1.2 Background

Modeling of systems and of events within systems in order to allow predictions about how the system will function has become a concern of the engineering, physical, and behavioral sciences. Models allow a representation of the events which take place within a system as a function of various external and internal variables. As such, they provide not only predictions about how the system under consideration will function but also an understanding about why the system will function in the predicted manner. Such information, of course, is of significant value to engineers and scientists concerned with system planning, design, and evaluation. The information derived from models is employed by planners and analysts in these and related disciplines for such purposes as personnel planning, system design and redesign, task structuring, safety analysis, training requirements derivation, and error analysis.

1.3 Purpose of MAPPS Computer Model

The MAPPS computer model was developed to provide the NRC and associated nuclear power scientists, engineers, architects, and plant operators with a tool for developing required insights relative to nuclear power plant maintenance. A principal focus of the model is to provide maintenance oriented human performance reliability data for PRA purposes.

MAPPS is a task-oriented, computer-based model for simulating nuclear power plant maintenance activities. It includes environmental, motivational, task, and organizational variables which influence personnel performance reliability and yields information such as predicted errors, personnel requirements, areas of maintainer stress and fatigue, performance time, and required maintainer ability levels for any corrective or preventive maintenance actions in nuclear power plants.

1.4 Foundation for MAPPS

The development of the MAPPS computer simulation model was based on the firm foundation provided by a front-end analysis and four job analyses. These analyses not only provided the information necessary for the design of the model but also stand on their own and provide insights into human factors aspects of nuclear power plant maintenance.

The front-end analysis (Ref. 2) investigated the need for such a model. Three user groups were identified: NRC personnel, nuclear power plant maintenance management personnel, and nuclear power plant architects and engineers. Semistructured interviews were conducted with representatives of these three groups, and a mail survey was completed with a total of 68 respondents across the three groups. The survey asked the potential users to indicate the types of information a maintenance model should provide. The results were used to select and design some of the model's input variables and the output information provided by the model.

In addition to the front-end analysis, job analyses of the positions of maintenance mechanic, instrument and control technician, electrician, and supervisor (Refs. 3,4,5,6) were completed. In these analyses, job incumbents, including supervisors, were asked to rate maintenance tasks on a number of dimensions, such as frequency of task performance, time and training requirements, consequences of inadequate task performance, and extent of intellective and perceptual-motor ability demand. Including all four analyses, data on 609 maintenance tasks were provided by 216 respondents representing 18 different commercial nuclear power plants. At the time that the job analyses were performed (1981-1982), they were the only existing analyses of their kind. The data were analyzed for their psychometric properties and were found to possess high rater reliability. The results of these analyses were used in the model's logics for calculating success probability and performance duration.

The initial model design was subjected to a peer review in December 1982. A panel composed of human factors psychologists, a reliability engineer, a nuclear engineer, and an industry representative (Institute of Nuclear Power Operations) reviewed the model's design, including the general modeling approach, the variables included, and the model's logic and processing. The modeling efforts received positive support and encouragement in both broad and specific areas from the review panel.

A second peer review was held at the end of the model development phase (December, 1983). A panel composed of subject matter experts in the areas of simulation modeling/field validation, computer science, and nuclear power plant maintenance operations reviewed the design implementation, the results of initial tests of the model, and evaluation/validation plans. Nuclear industry as well as NRC representatives were present at this review. This panel endorsed the modeling approach and provided positive support for the plans for model evaluation/validation.

1.5 Organization and Content of the MAPPS Model

The global purpose of the MAPPS model is to allow quantitative analysis of the effects of varying a set of conditions represented by model inputs on a second set of conditions or analytic results. The input conditions can be varied one at a time, or in any combination, by the user at a computer terminal. The analytic results are provided at various levels of detail, as selected by the user. Generally, all the results are available in summary form. A user can design his numerical experiments consisting of one or more runs* and be presented with data representing all elements of results from which he can develop relationships, gain interdependency insights, and draw hypotheses and conclusions about various aspects of nuclear power plant maintenance.

Briefly, and by way of overview, for the maintenance task to be simulated, input data of three types—variable (parameter), task, and subtask—are entered by the analyst.** Variables represent the conditions under which the simulated maintenance team is to work and the characteristics of selected maintenance technicians. The model allows for the simulation of up to five different maintenance job specialties—instrument and control technician, maintenance mechanic, electrician, supervisor, quality control***—plus a control room operator.*** Task information represents a set of data relative to the task as a whole while subtask information describes the characteristics of each subtask involved in task completion.****

Acting on these data, the model sequentially simulates the performance of each subtask involved in total task completion according to the logic described in Chapters 3 and 4 and fully elaborated in Reference 1. Within the logic, the following concepts are included during the simulation of each subtask: difference between the intellective and perceptual-motor abilities required for subtask completion and the actual abilities of the maintenance technicians simulated, technician fatigue, time stress, performance decrement due to high environmental temperature, stress induced by faulty communication, fatigue relief due to rest breaks, presence of radiation, technician's level of aspiration, quality of written procedures for supporting performance, supervisor's expectancy about the quality of performance, accessibility, wearing of protective clothing, time since the various team members

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*A run is composed of multiple iterations (simulations) of a task.

**For some tasks, the required subtask data are already embedded in a "task library."

*** Only *interactions* with these job specialities are simulated within MAPPS.

**** An optional preprocessing feature, embedded in the model's program, avoids the need for individual entry of some subtask detail. Default values are also provided by the model to allow for the omission of some other detail.

performed the task, organizational climate, and whether or not the actual manning is greater or less than the required manning. These interact within the MAPPS model in accordance with the flow logic which includes random sampling (stochastic) techniques to account for intra- and inter-individual, situational, and contextual differences.

Depending on the result of the simulation of any subtask and the input data, the model either proceeds to the simulation of the next subtask, repeats the simulation of the subtask, loops ahead or back in the subtask sequence, or branches into a new subtask sequence.

A provision is also incorporated within the simulation for the simulated maintenance team to skip a subtask when the stress level is high and subtask completion is not essential for task completion.

This procedure continues serially for each subtask in the task completion sequence until the last subtask in the task sequence has been addressed by the simulated maintenance team. The model then simulates the performance of the task again and continues with resimulations until a specified number of full task simulations has been completed. This reiteration is necessary because a number of simulations is necessary to smooth the random effects introduced into each individual task simulation (iteration).

During the course of the simulation, a variety of data is compiled. These data are grouped into four categories and displayed in summary table form. Because not all categories of available output data will usually be wanted by the analyst, the analyst is provided with the capability for selecting any output option category mix which meets the analyst's requirements.

1.6 Decision Making and Trouble-Shooting

Because of their special importance to nuclear power plants in general and their specific relevance to maintenance, the MAPPS model contains two special subroutines—decision making and trouble-shooting. These are included to allow special consideration of subtasks which are preponderantly cognitive in nature as opposed to normal action maintenance subtasks which include a considerable perceptual-motor loading. Trouble-shooting refers to the process of diagnosing the cause of a malfunction and decision making refers to the process of selecting among alternative courses of action. When one or the other of these types of subtasks is reached during the simulation of the subtask sequence, a unique processing is instituted according to a logic especially developed for these subtask types. The basis for these logics, the logics, and their implementation within the MAPPS model is fully presented in Chapters 2 and 3 of Volume 2 (Ref. 1).

1.7 Emergency Events

The MAPPS model also allows for the superimposition of emergency events on the normal subtask sequence in order to allow the analyst to determine the effects on maintenance task performance of an outside emergency which occurs during the performance of a given maintenance action. If an emergency is to be considered during the simulated task performance, an input indicator is set by the analyst along with the mean duration of the emergency. MAPPS then automatically enters the emergency into the subtask sequence and the simulation accounts for the effects of the emergency on the performance of the primary maintenance task.

1.8 Applicability

MAPPS is a general stochastic subtask driven computer simulation model believed to be applicable to any type of nuclear power plant. The model provides the capability to simulate:

- corrective as well as preventive maintenance tasks
- contractor as well as "in-house" maintenance
- maintenance conducted by personnel with any combination of skills and job titles who are working under any conditions usually encountered
- special subtask types (decision making and trouble-shooting) as well as normal actions subtasks

The model also allows for:

- customized task analysis data for each simulated maintenance task
- calculated (not input) values for average subtask durations and success probabilities
- the use of default data when selected inputs are not provided by the user
- replacement (rotation) of maintenance personnel
- the partial use of a Monte Carlo approach for most functions—to introduce chance elements
- operating via interactive computer terminal; providing results at the terminal and on a local or a remote computer line printer
- generating a variety of selectable output options at various levels of detail.

MAPPS allows the analyst to vary systematically, both individually and in combination, a variety of conditions (tasks, variables, technician ability level variables, environmental and situational variables, and human factors variables) to yield subtask, shift, iteration, and summary (task) data. These data show the effects of the variations introduced by the analyst on the simulated task performance and can provide, at least in part, a basis for trade-offs, regulatory decisions, and augmenting PRA analyses.

1.9 User Features

From the outset, it was recognized that the ultimate implementation and use of the MAPPS model would depend on how convenient it is for the user to employ the model. Accordingly, full emphasis was placed on convenience features during the model's design.

Required analyst input information is entered via tabular menus which are logically organized and prompted by means of descriptive statements and permissible (tolerance) ranges. Moreover, default values are automatically provided to allow for the case in which the analyst forgets or misses a required entry. In addition, error messages are automatically generated throughout the program. These assist the user in the identification and correction of errors.

There are a number of equipment configuration modes in which the model will function: on-line terminal, on-line terminal and printer, and on-line terminal and remote printer. Moreover, simulations may be performed in either the batch or the individual run modes of operation. Accordingly, considerable flexibility is available to the user.

The number of key strokes required to enter data/commands is minimized by the use of function keys. Similarly, the procedures for entering into and exiting from (log-on and log-off) the model were kept to a minimum number of essential steps and key strokes.

While the computer running time for a given task will vary as a function of the number of subtasks involved, the number of iterations involved in a simulation run, the amount of output detail requested, and the specific characteristics of the individual user's installation, about two seconds of computational time are required for one iteration of a task involving 36 subtasks.

The output has been similarly organized for convenience in tabular and easy to read form.

A full user's manual will be provided. This manual will provide step-by-step procedures for implementing the model and for integrating the results of any simulation run or set of runs.

Other planned features for providing smooth adoption and application of the MAPPS model include: development and administration of a formal user training program, a telephone service to answer user questions, and extension of the output to graphic form.

Other convenience features could be incorporated but are not currently anticipated for implementation. These include a procedure for ongoing code enhancement and program maintenance and a procedure for correcting program errors.

1.10 Model Sensitivity Test

After the model was developed in preliminary form, it was subjected to a set of tests in order to evaluate the reasonableness of its output and the output trends when the input data are systematically varied. These tests included both hand calculations and formal model runs. The results of such tests allow statements about the sensitivity of the model to input variation and about the reasonableness of the model's output. During and after the initial MAPPS sensitivity test simulation runs, some internal adjustments and calibrations were introduced into the model. The complete results of these tests are presented in Chapter 3 of Volume 2 (Ref. 1). Table 1.1 presents a partial listing of the model sensitivity tests which were completed along with a qualitative description of the results

Table 1.1. Summary of Sensitivity Test Results[1]

Variable	Conditions Tested	Results				
		Task Duration	Success Proportion	Undetected Errors	Maximum Stress[2]	Effectiveness[3]
Intellective Ability	Low to High	↓	↑	--	↓	↑
Perceptual-Motor Ability	Low to High	↓	↑	--	↓	↑
Stress Threshold[4]	Low to High	--	↑	↓	--	↑
Supervisor Acceptance	Low to High	↑	↓	↑	↑	↓
Time Limit	5,6,7,8 hours	*	↑	↓	↓	↑
Prior Work (fatigue)	0,4,20 hours	--	↓	↑	↑	--
Temperature	70,90,110°F	↑	↑	--	--	↓

Note 1: Arrows indicate direction of change as variable value was increased from lowest to highest value. Dashes indicate changes of less than 10 percent or curvilinear relationships. Asterisk indicates an indeterminate result.

Note 2: Average maximum stress (over 50 iterations) on the simulated maintenance team.

Note 3: Defined as a function of performance quality and time.

Note 4: Point at which technician performance starts to degrade because of high current stress level.

obtained relative to selected performance indices. The arrows in Table 1.1 indicate the directionality of performance change as indicated by MAPPS. Absolute values of the magnitude of change are given in Chapter 3 of Volume 2 (Ref. 1).

1.11 Model Evaluation

An extensive evaluation of the MAPPS model will be undertaken in the calendar year 1984. The evaluation will consider empirical model validity issues as well as model practicality, acceptability, and usefulness. Model practicality includes such issues as the cost of ownership, personnel and training requirements, portability, compatibility, and model operating requirements. Model acceptability refers to the reaction of potential users to the model, including risk assessment analysts, the NRC, and utilities personnel. Model usefulness includes such model issues as completeness, robustness, and expandability.

1.12 Content of Subsequent Chapters

Chapter 2 of this report provides background information on major issues in behavioral simulation modeling. Chapter 3 describes the constructs built into the MAPPS model and how the constructs are integrated into a fully articulated model, their representation, and interactions. Chapter 4 describes the processing sequence and the processing. The reader who wishes fuller detail about the theoretic basis for the representations, their mathematical formulations, and their implementations is referred to Chapter 1 and 2 of Volume 2 (Ref. 1). Chapter 5 presents some of the reasons for confidence that the model seems to achieve its goals and discusses the implications of the work.

The chapters of this volume and of Volume 2 (Ref. 1) describe the model in its August 1983 form. The sensitivity test description and results, presented in Volume 2 (Ref. 1), are based on the model's architecture at that time.

2. BACKGROUND AND NEED

2.1 Computer Simulation Modeling

In the general case, a model is a representation of a system and the events which take place in the system. Frequently, the model takes the form of a descriptive representation which portrays significant variables and the flow of data and information among them. In some models, the paths among the variables represent cause-effect relationships while in other cases the paths represent hypothetical associations among and between variables.

As a special type of model, computer simulation models extend descriptive models. They allow the user or analyst to vary the quantity, type, and/or level (or some combination thereof) of the variables within the system represented and, as a result, determine the effects of this variation on system output. Because a large number of variables and interactions is usually involved, the simulation model is usually programmed for implementation on a high speed digital computer.

2.2 Prior Behavioral Science Digital Simulation Models

Digital simulation models are not new to the physical or the behavioral sciences. Siegel and Wolf (Ref. 7) reviewed prior behavioral science simulation methods for meeting these problems. Issues which they discussed included: the type of model to construct, time and event advance techniques, input data requirements, data availability, transportability, model validation, generality, the model-user interface, cost/effectiveness considerations, individual differences representation, and parameter estimation and choice.

They concluded that:

> 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 recommend the use of the technique, as do current texts in human factors engineering. For human involved systems, various agencies have come to rely more and more on the use of such models. All of these applications include circumstances in which the use of other types of predictive methods are untenable, uneconomical, or impossible (page 81 of Ref. 7).

In another contemporary review of simulation modeling and available models, Siegel *et al.* (Ref. 2) described and considered various available methods for assessing human performance reliability in nuclear power plants. They included simulation models within their analyses and indicated that the advantages of simulation models over more deterministic techniques appear to be that simulation models allow the capability for:

1. Analysis and prediction which considers the inherent variability both between and within individuals. (This feature seems particularly important to nuclear power plant analysis where requirements and technician proficiency may vary both across and within plants.)
2. Considering a large number of equipment, environmental, and personal variables independently and in combination. (The number of possible interactions in complex systems, such as nuclear power plants, is very large and cannot be handled efficiently by other analytic methods. In addition, trade-off curves between variables can be generated.)
3. Providing prescriptive (what should be done) as well as diagnostic (what seems to be the problem) information.
4. Considering in a realistic manner both the "normal" and the "degraded" condition for both the personnel and the equipment in a system.
5. Providing results in the form of distributions rather than as point estimates.
6. Considering a current system, hypothetical variations of the system, and alternative systems.
7. Allowing random events to be superimposed on normal event sequences.
8. Providing results of a variety of types and at a variety of levels. (For example, task completion time, success probability, error rate, and error type data can be provided by person, shift, day, and extended time period.)
9. Dynamically considering the time-varying characteristics of humans. (For example, humans learn, become fatigued, gain or lose motivation, and respond to stress.)

They recommended that:

> ...if a formalized, quantitative, predictive methodology for the analysis of nuclear power plant maintenance personnel reliability is to be developed, it should be of the simulation type.

The value of simulation models was also supported by Adams (Ref. 8) who, in discussing issues in human reliability, wrote: "There is a development that shows promise for remedying some of the problems that have been discussed. Monte Carlo modeling of person-machine systems can include human and equipment variables; it is versatile and not bound by hard to meet assumptions." Similarly, Meister (Ref. 9) wrote "..., like Adams, I find...the simulation modeling approach to be promising..."

2.3 Examples of Prior Behavioral Simulation Models

Prior behavioral simulation models have been developed in a variety of contexts and have included a diversity of behaviorally and system oriented variables.

The first integrated attempt at behavioral modeling on the basis of high speed computer applications is believed to be that of Siegel and Wolf (Ref. 10). 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 were successfully 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 technology progressed and confidence in its power increased, more variables and variables of increased complexity have been included in such simulations. For example, one battle simulation model (Ref. 11) includes the effects on performance of "physical" variables such as light level, terrain advantage, and enemy/friendly personnel ratio. Other simulation models (Refs. 12, 13) have included consideration of such variables as group cohesiveness, group morale, leadership, and learning. The Army's NETMAN model (Ref. 14), developed to simulate message processing in command and control systems, includes decision making and level of aspiration simulation subroutines.

Current simulation models, which are somewhat less behaviorally oriented and more oriented towards consideration of the physical activities of system operators, include a model developed by Boeing to evaluate the physical workload on aircrew members (Ref. 15) and HOS (the Human Operator Simulator) (Ref. 16), developed by the Navy, which essentially completes a task analysis and provides the user with detailed information in a summary task analytic form. Askren and Lintz's model (Ref. 17) is essentially a highly sophisticated logistic model built by the Air Force to predict aircraft maintenance time. PROCRU (Procedure Oriented Crew), another Air Force simulation model (Ref. 18), simulates flight crew procedures during approach to landing and incorporates both procedure and rule based behaviors. Kleinman, Baron, and Levinson (Ref. 19) conceptualized an operator control model which seems to be drawn from Sheridan's (Ref. 20) supervisory control model. The model of Kleinman *et al.* postulates a complex system operator interaction and includes cognitive and perceptual considerations.

2.4 Maintenance Cost and Problems in Nuclear Power Plants

While rapid, thorough, and accurate operator performance is accepted as essential for operating nuclear power plants in a safe and effective manner, the role of maintenance and of maintainer performance has received less research attention. Yet, anecdotal and statistical information, as emphasized in the following quotations strongly supports the contention that maintainer activity can contribute heavily to safety degradation and cost-effective operation.

- According to investigators from the NRC, the ultimate cause of the steam leak at the Robert E. Ginna plant last January may have been poor workmanship (Ref. 21).
- The 15.4 percent of the plant reports which clearly identify personnel involvement consisted of 57 operator-related incidents and 50 maintenance incidents (Ref. 22).
- Testing and maintenance errors are found to be more important than operator errors in the determination of core melt probability (Ref. 23).

Similarly an analysis of Licensee Event Reports, presented by Mays and Gallaher (Ref. 24), for the period of September 1 through October 28, 1982 indicated that, during the time interval involved, at least the following maintenance associated events resulted in reactor shutdown.

Report/Event	Event	Cause
070282 060582	Reactor shutdown due to loss of three essential buses	Improperly calibrated under voltage relay
081182 060582	Update on loss of all 480 volt essential buses	Undervoltage relay improperly calibrated
080582 060582	Update on control valve failure to fast close	Maintenance personnel error
072282 072282	Reactor shutdown twice due to power channel rate meter problems	Dirty switches and amplifier boards

Similarly, Joos, Sabri, and Husseiny (Ref. 25) analyzed reportable nuclear power plant incidents during the period of June 1, 1973 through June 30, 1975 and reported the occurrence of human errors within the incidents. The probability of total maintenance error, as derived from their analysis, was .06, .10, and .08 for pressurized water reactor, boiling water reactor, and all light water reactor plants, respectively.

2.5 Maintenance Model for Nuclear Power Plants

While a number of available computer simulation models exist, prior computer simulation models have been almost exclusively concerned with operator activity and with closed loop situations involving precise response in brief time frames (e.g., flying an aircraft). Nuclear power plant maintenance, on the other hand, is largely open loop in nature and, in most cases, time constraints are not critical. Moreover, the environmental, personnel, and task characteristics in maintenance are partially unique to maintenance situations. General operator models would probably fail to include variables which are important to nuclear power plant maintenance.

Accordingly, a front-end analysis was undertaken to determine the need for and required characteristics within a maintenance model which will predict the effectiveness of nuclear power plant maintenance activity (Ref. 2). Structured interviews were completed with 30 representatives of nuclear power plants, the NRC, and architect/engineer organizations. Additionally, formal questionnaires were completed by 68 plant, NRC, and architect/engineer representatives. The report of the analysis detailed the need for and usefulness of information in a wide variety of maintenance areas and indicated that the maintenance predictive information which would be most useful to nuclear power regulators, planners, and system designers include data about:

- the relationship between training and maintainer performance proficiency
- the presence and causes of undetected errors
- preferred maintenance team composition
- time to complete maintenance tasks and error rates
- methods for minimizing radiation exposure levels

The report concluded that in the maintenance context:

- a computer simulation model would prove very useful to a variety of safety interest purposes
- such a model should provide a wide variety of output data and be rich in internal variables
- the internal variables should include, but not be limited to: environmental conditions, maintainer ability, physical factors, and performance moderating variables (e.g., stress, fatigue, heat)
- the model should be applicable to the maintenance activities of all nuclear power plants and should yield output at both the subtask and the task levels

Finally, the report recommended that:

> Because of: (1) the potential of such a model for nuclear power plant maintenance analytic purposes, (2) the perceived utility of such a model as expressed by the participants in the survey and by the interviewees, and (3) the relatively low risk of a model development effort, completion of initial work towards the design of a nuclear power plant maintenance performance reliability model is recommended.

2.5.1 Relationship of Computer Modeling to Reliability Analysis and to Probabilistic Risk Assessment

In a very specific sense, a maintenance computer simulation model would attempt to predict the probability of an error during the performance of a maintenance task where successful maintenance task performance is defined as completion of the set of subtasks associated with a given repair, replacement, or equipment maintenance activity performed under specific environmental conditions by personnel possessing defined proficiency. As such, the computer model would represent a technique for assessing human performance reliability. Human performance reliability attempts to state the probability of a human failure. Within the system analysis context, system reliability may be conceived as the joint probability of a human and an equipment failure. Computer modeling can provide the data for stating the probability of human failure in such analyses.

Probabilistic risk assessment extends reliability analysis and involves developing a set of possible accident sequences and determining their outcome. A joint report of the American Nuclear Society and the Institute of Electrical and Electronic Engineers (Ref. 26) indicated that, to achieve its goals, probabilistic risk assessment develops and analyzes several sets of models:

- Plant-system models, generally consisting of event trees, which depict initiating events and combinations of system successes and failures, and fault trees, which depict ways in which the system failures represented in the event trees can occur.
- Containment models which represent the events occurring after the accident but before the release of radioactive material from containment.
- Environmental transport and consequences models which represent the outcome of an accident in terms of public-health effects and economic losses.

It is evident that human performance is integral to any of the above three model types and that, if such probabilistic risk assessment models are to be complete, human performance models must be available. Such human performance models can be either integrated within the probabilistic risk assessment models or the output of the human performance models can be compounded with the output of the probabilistic risk assessment models to yield outcome estimates based on human and equipment system considerations.

2.5.2 Other Uses of Computer Simulation Models in the Nuclear Regulatory Context

While computer simulation models can be valuable for augmenting probabilistic risk assessment techniques and hence doing away with the sometimes assumed zero probability of human failure within such techniques, human behavioral simulation models can also provide a variety of unique data of use to regulators, designers, and operators of nuclear power plants. This follows because simulation models consider in interaction a wide variety of personnel, system, and environmental variables. The output of the MAPPS model, described in later sections of this report, provides data which can form at least a partial basis for manning, scheduling, selection, training, and other regulation oriented decisions. Other specific uses of the information provided by MAPPS include but are not limited to: (1) maintenance system design evaluation (e.g., estimating time to repair existing systems, identifying maintainability problems in existing systems, evaluating maintenance procedures), (2) maintenance operations analysis (e.g., comparison and optimization of maintenance strategies, maintenance planning/ scheduling), and (3) contributing data for a human factors data store.

3. DESCRIPTION OF MAPPS

This chapter presents a description of the MAPPS computer model from the points-of-view of its use and its logic. The functions and characteristics of the major subroutines which comprise the model are described. These descriptions are summary in nature. The full theoretic bases for the model, its programming requirements, data items, logic equations, and the organization of the program into subroutines are found in Chapters 2 and 3 of Reference 1.

3.1 Model Use

The user, as the initiator of model application, selects the task(s) to be simulated and provides the conditions for simulation. Employing a computer terminal, these data are entered/verified/monitored (or prestored conditions are confirmed) via the terminal's screen. Table 3.1 defines the range of values for key model elements and serves to define the scope and limits of the current version of the MAPPS simulation model. Figure 3.1 shows the global elements in the utilization of the MAPPS model.

Table 3.1 indicates the capacity to simulate at any time, one of up to 200 maintenance tasks performed by a "team" of two through eight maintainers consisting of any or all of five selected maintainer types (mechanic, instrument and control technician, electrician, quality control,* supervisor, and control room operator*). The team may "perform" a series of up to 100 subtasks comprising the selected maintenance task. The model provides for up to 28 kinds of maintenance subtasks. The simulated task performance can require up to two days of real time and this maintenance period may be divided into as many as 10 shifts (personnel rotations). Each subtask is performed by a "work group," i.e., all or a subset of the members of the team. Maintainers may don or doff protective clothing representing up to three levels of "protection." The model recognizes two types of ability within individual maintainers and teams: (1) intellective, and (2) perceptual-motor.

Table 3.1. Model's Scope

Feature	Model Limit
Maximum number of tasks	200
Number of maintainers	2-8
Types of maintainers	5
Number of subtasks	100
Types of subtasks	28
Maximum task duration (days)	2
Number of shifts	1-10
Categories of protective clothing	3
Types of ability	2

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* Only interactions with these job specialties are simulated within MAPPS.

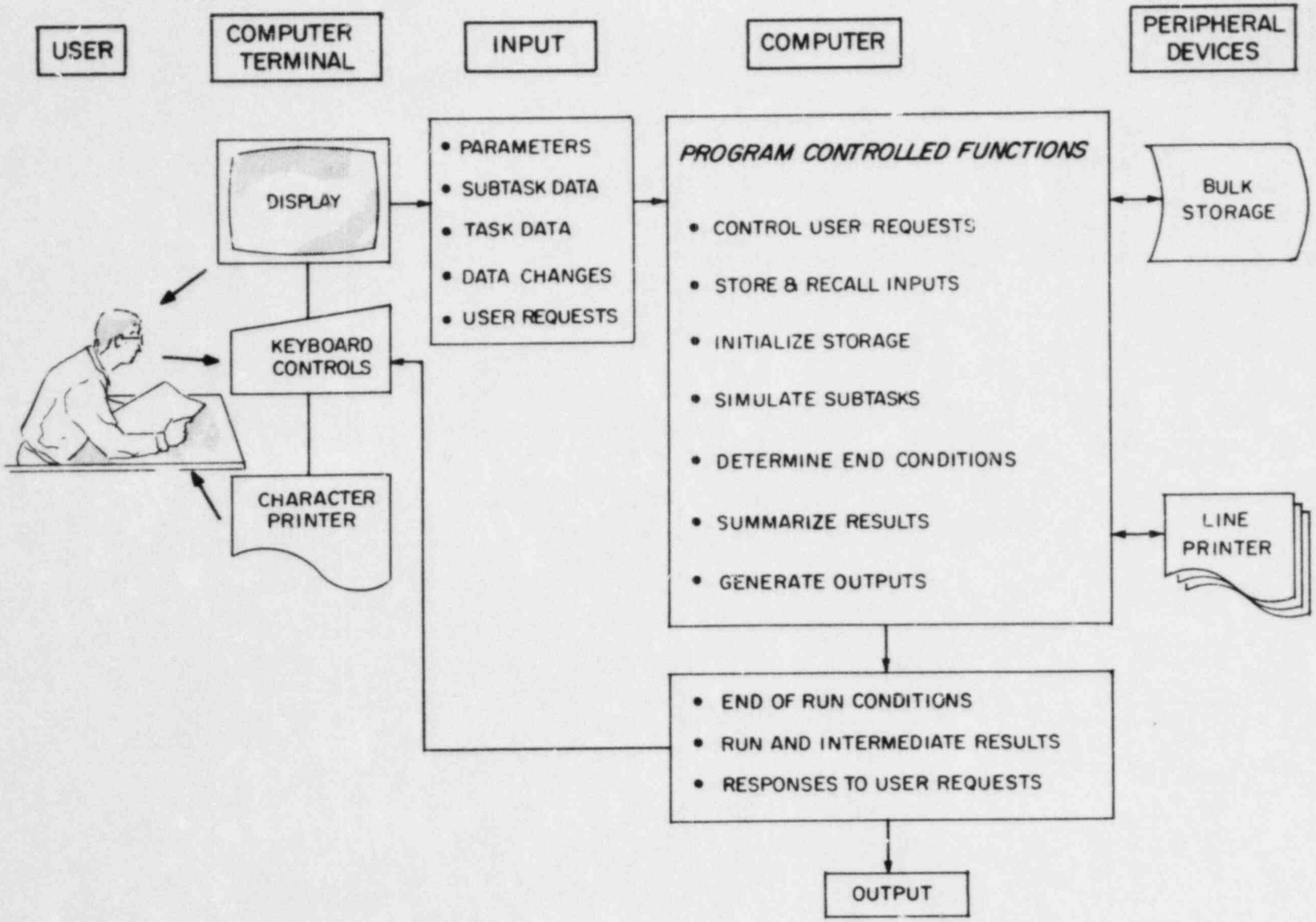

Fig. 3.1. Global Elements of the MAPPS Model.

The model provides for simulating the individual characteristics of the maintainers and, within the simulation, each such characteristic is altered as a function of events that transpire and conditions that exist. The workplace, maintainer, motivational, human factors, subtask, and task oriented variables are listed in Table 3.2.

3.2 Basis for Variable Selection

Variable selection represents a major design decision in the development of a simulation model. To a certain extent, judgment must be exercised concerning the inclusion of potential variables within a model.

To select the variables included in the MAPPS model the front-end analysis and job analyses, previously mentioned in Section 2.5, served to produce an initial list of potential model variables. This list was supplemented by a set of variables derived from a literature analysis relative to job performance and by another set of variables drawn from the technical modeling experience of the developers of the MAPPS model. The total list was then screened on the basis of the following criteria:

- Relevance to nuclear power plant maintenance
- Empirical support
- Amenability to objective measurement and quantification
- Generality
- Uniqueness
- Utility
- Freedom from triviality
- Heuristic value

The results of the multiple screening were the list of variables given in Table 3.2 which also presents the source(s) of each of the selected variables.

3.3 Simulation Procedure

The processing within the MAPPS computer model revolves around a sequential simulation of the subtasks which constitute the task being simulated. The MAPPS computer program performs a variety of ancillary functions such as initializing variables, processing user requests, and providing tabularized output summaries. These are described in the final section of this chapter and in Chapter 4.

Figure 3.2 presents an overview flow chart of the logic of the basic simulation and is applicable to all subtasks except "donning," "doffing," "decision making," "trouble-shooting," and "rest" subtasks (special subtasks). The simulation of these special subtasks is discussed subsequently in Section 3.3.6 headed "Special Subtask Simulation."

Table 3.2. Variables Included in the MAPPS Model and the Basis for Their Inclusion

Variable Type	Variable	Basis for Inclusion		
		Front-End Analysis	Literature	Modeling Experience
Workplace	Temperature	X	X	
	Radiation	X		
	Noise	X	X	
Maintainer	Fatigue	X	X	X
	Intellective Ability	X	X	
	Perceptual-Motor Ability	X	X	
	Time Since Last Performance		X	
	Supervisor's Acceptance		X	
	Stress Threshold	X	X	X
	Overmanning	X		
Motivational	Aspiration Level	X	X	X
	Supervisor's Aspiration		X	
	Organizational Climate	X	X	
Human Factors	Accessibility	X	X	
	Protective Clothing	X	X	
	Procedures Quality	X	X	
Subtask	Intellective Requirements	X	X	
	Perceptual-Motor Requirements	X	X	
	Communication	X	X	
	Essentiality			X
Task	Time Limit	X	X	X
	Time Limit Importance	X	X	X
	Number of Maintainers by Type	X		X
	Risk Weight	X		
	Shift Change			X

The overall purpose of the subtask simulation is to determine: (1) whether or not the subtask is performed successfully, (2) whether or not an undetected error exists in the work, and (3) how much time is involved in completing the subtask. To these ends, MAPPS considers the previously listed variables which interact within the logic to yield the required output. The effects of all the variables listed in Table 3.2 are reflected in this aspect of the model.

On the general level, the subtask simulation is based on a broad set of axioms:

1. Subtask success probability and performance duration vary as a function of the difference between the ability requirements of a subtask and the actual ability of the maintainers. As the abilities of the maintainers approach or exceed the ability requirements of a subtask, the subtask success probability increases and the performance time decreases.

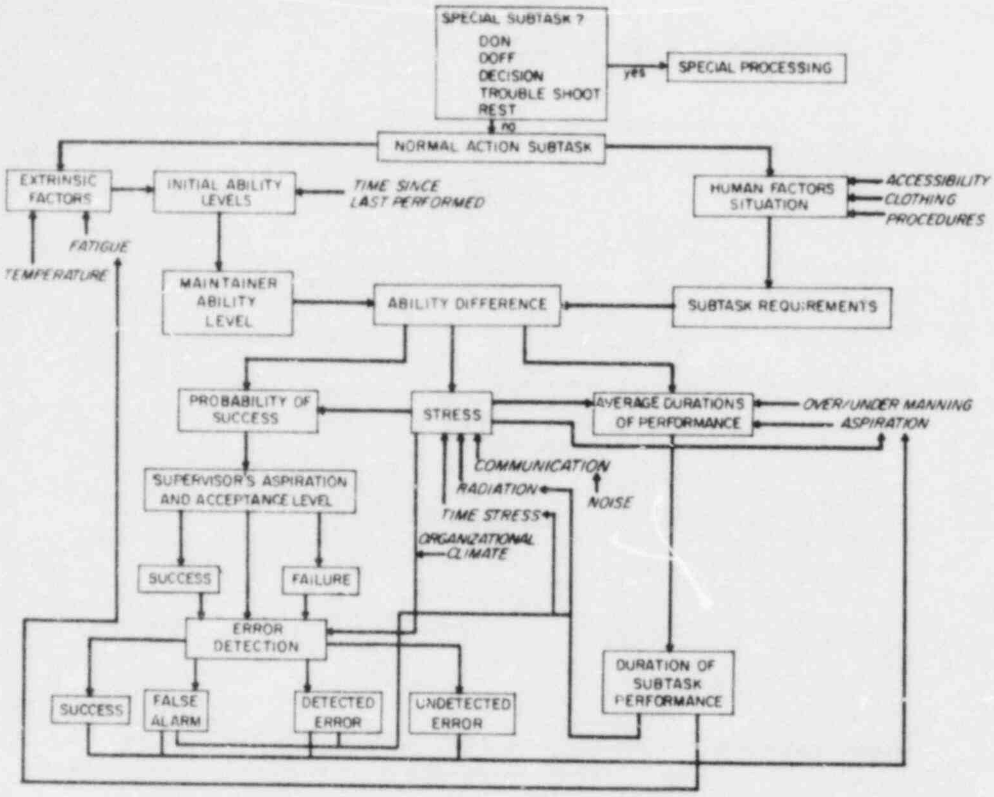

Fig. 3.2. Overview of Logic Flow Within MAPPS Model.

2. Stress on the maintainers affects success probability and performance duration. "Moderate" stress increases subtask success probability and decreases performance time; "high" stress (i.e., stress above the stress thresholds of the members of the simulated work group) decreases the success probability.

3. When the workplace temperature exceeds 80 degrees Fahrenheit, performance quality will degrade as a function of the level of the heightened temperature.

4. When maintainers know that the radiation level to which they will be exposed during task performance is such that their total absorbed dose will approach or be greater than their quarterly allowance, they will tend to increase their work pace (to decrease their exposure).

5. Poor component accessibility, inferior procedural aids, and protective clothing tend to make maintainer performance slower and less accurate.

6. Fatigue and nonrecent performance of a task negatively affect performance time and work quality.
7. The supervisor's requirements relative to work quality will determine whether or not a work-group's performance of a subtask is "acceptable" or "unacceptable."
8. Work groups with high levels of aspiration working for supervisors with high levels of aspiration will perform more quickly and thoroughly.
9. A favorable organizational climate reinforces productivity.
10. If communication is required during the course of the performance of a subtask, subtask performance will degrade as a function of conditions which fail to support communication.

3.3.1 Ability Difference

As indicated in Figure 3.2, the subtask simulation subroutine first considers how long each of the simulated maintainers has worked prior to this subtask (i.e., fatigue level) and the temperature level of the workplace. The current ability level of each maintainer is adjusted on the basis of these considerations.

In a parallel calculation, the human factors situation is assessed relative to the subtask under consideration. Specifically, the accessibility of the equipment to be worked on, the effects of wearing protective clothing on job performance requirements, and the adequacy of the job aids (procedures) for supporting technician performance are considered. When one, several, or all of these are "negative," the perceptual-motor requirements for task performance (from stored information) are increased.

Accordingly, the MAPPS program has, at this juncture, calculated the current ability level of each maintainer and the required ability for completing the subtask. Comparison of the two yields an ability difference of "ability load." The ability load serves as one part of a stress calculation which subsequently affects success probability and the time required for subtask completion.

3.3.2 Success Probability

The MAPPS model is not dependent on the availability of a subtask success probability as an input value. If such data are available and provided as input to the simulation, MAPPS modifies this value on the basis of the ability difference variable described above. If no input subtask success probability is provided, the ability difference value is entered into an algorithm which generates an initial success probability.

3.3.3 Total Stress

The total stress on the simulated work group is affected by the ability difference value as well as by time stress, radiation presence, and communication problems (if present).

Time stress. When the time required to perform all remaining subtasks is greater than the time available for total task completion, time stress is assumed to be present and its level is calculated.

Radiation stress. When the absorbed radiation dose for a given technician will be greater than 800 millirem (mrem) during the course of task completion, radiation stress is augmented. The NRC's maximum permissible quarterly dose is 1250 mrem per quarter.

Communication stress. If communication is an ingredient in subtask performance, the stress resulting from any communication degradation is considered. This stress increases as a function of one, several, or all of the following conditions: (1) elevated noise level in the work area, (2) length of the involved communications, and (3) the total number of technicians in the work group.

Once the four individual stress components (ability difference, time, radiation, and communication stress) are individually calculated, the total stress on the simulated technicians during the simulated performance of the subtask under consideration is calculated.

The total stress is then compared with the input stress thresholds of the simulated technicians to determine the effects of stress on subtask success probability and on performance duration. If the total stress is at moderate but below threshold levels, subtask success probability increases and subtask completion time decreases; in both cases standard deviations decrease. When the total stress is above threshold, the success probability decreases and its standard deviation increases.

3.3.4 Subtask Outcome and Error Detection

The moderated success probability is next employed to determine whether or not the performance of the subtask may be considered to be a success or a failure in an "absolute" sense. To this end, the moderated success probability is compared with the quality of work which the supervisor will accept. The supervisor's acceptance level is provided as an input variable and, if the moderated probability is greater than the acceptance level, the subtask is assumed to have been performed successfully and at an acceptable quality level. Otherwise, a subtask failure is assumed to have occurred. Following the determination of subtask success or failure, the error detection logic is entered. The logic flows from input values of probability of error detection. The model makes an adjustment to the input error detection probability on the basis of: (1) whether the organizational climate is "favorable," "unfavorable" or "indifferent," (2) the time stress level, and (3) the stress thresholds of the members of the simulated work group. Positive sets of conditions increase error detection probability while negative sets of conditions serve to decrease error detection probability.

If the simulated subtask performance has been successful and a quality control check is called for, the simulation then determines whether or not the quality control personnel accept the quality of work. This determination is made on the basis of the moderated error detection probability and a stochastic process. Quality control rejection now causes the subtask performance to be termed a "failure."

In the case of a subtask success, after update of the radiation and aspiration variables, the simulation proceeds to the next subtask as indicated by the input information. In the case of failure, the simulation of the subtask is repeated (or a branching sequence may be entered). Up to three repetitions of a subtask are allowed. If a subtask is failed on three successive trials, a total task failure is assumed to occur. The possibility also exists that although the subtask has been successfully accomplished, the simulated work group will "think" that an error was committed during the performance. MAPPS calls this a "false alarm" and, in this case, causes the subtask performance to be repeated as for a failed subtask.

In the case of a subtask failure, an additional check is performed to determine whether or not the error in the work has been detected by either the work group, the supervisor, or the quality control personnel. If the error has not been perceived by any of these, subtask repetition does not take place and the simulation proceeds as if the subtask was successfully performed. In this case, however, the undetected error is noted by MAPPS and a total task failure is registered.

3.3.5 Subtask Performance Time

The calculation of subtask performance time, the second major output of the subtask simulation subroutine, is also influenced by the ability difference calculation described previously. Once the ability difference is calculated, several additional considerations enter into the initial determination of performance time:

- *Overmanning.* If the subtask is overmanned, performance time is appropriately decreased.
- *Aspiration.* Depending on whether or not the stress level is above the stress thresholds of the maintainers and whether or not the difference between the maintainers' level of aspiration and the supervisor's level of aspiration is positive or negative, there is an appropriate adjustment of performance time. Favorable sets of these conditions serve to decrease performance time while unfavorable sets of conditions serve to increase performance time. There is no adjustment in the cases of neutral sets of conditions.
- *Total Stress.* Subtask duration decreases with increases in total stress when the total stress is below the stress threshold of the simulated maintainer(s). When the total stress is above the threshold value(s), increases in the total stress lead to longer subtask durations.
- *Ability Difference.* Positive differences between maintainer ability and the ability required for subtask completion lead to shorter subtask durations while negative ability difference values lead to greater subtask durations.

3.3.6 Special Subtask Simulation

The primary simulation described above is applicable to all subtasks except protective clothing donning and doffing, decision making, trouble-shooting, and rest. These types of subtasks receive special processing:

Donning and Doffing of Protective Clothing. The special processing for the donning and doffing of protective clothing is concerned with the selection of the personnel who will don or doff the protective clothing. The MAPPS logic in the case of donning calls for donning the required clothing if the personnel types and numbers required for completing a subtask are not already protected. The simulated technician(s) of the required type(s) is (are) selected who have worked the least up to this point. Otherwise the simulation proceeds as described above. In the case of doffing, personnel who have worked the longest are selected first for the removal of protective clothing. The need for donning and doffing are indicated by input data.

Decision Making. Decision making subtasks are modeled as a process of choosing among competing alternatives. The decision making logic is partially deterministic in nature. Influences on the quality of decision making result from the decision maker's level of intellective ability, decision complexity, and stress. On the basis of input which specifies decision goals, number of alternatives, and the effects of each alternative on the goals, MAPPS generates a matrix which represents the "problem solving space." The "space" is composed of information acquisition points and courses of action (decisions). The simulated decision maker may pass from any information acquisition point to any other acquisition point or from any acquisition point to a final decision. These movements are probabilistic but influenced by the utilities of the alternatives and the decision maker's intellective ability level.

Decision complexity is based on the similarity among the transition probabilities. If one alternative has a high transition probability, the decision could be described as "easy" and is made quickly. If all alternatives and information acquisition points have similar transition probabilities, the decision is more difficult and the decision maker may repeatedly pass from acquisition point to acquisition point before a final solution is reached. Each transition requires an amount of time. The final decision time is the sum of the transition durations.

Trouble-Shooting. Trouble-shooting (fault diagnosis) within MAPPS is treated as a cognitive process involving search and comparison. The trouble-shooting subtask simulates this process of search and comparison.

The simulation starts with a consideration of the accuracy, thoroughness, and validity of the trouble-report. This information (K) is then successfully compared with analogous patterns known to result from five potential malfunction causes (C_1 through C_5). The diagnostic decision is based on the smallest difference between K and C_1 through C_5, i.e., the C_j most closely matching K (the diagnostician's notion of the trouble) is designated the probable cause of the reported trouble. The result is a statement of whether or not the correct cause has been identified and the time to complete the diagnosis. Supervisor ability level and organizational climate are also considered within the trouble-shooting subtask simulation.

Rest. Rest subtasks lower the fatigue level of all maintainers in the simulated work group. When a rest subtask is called for by input, all technicians are rested concomitantly and all receive the same rest duration. Fatigue relief for each simulated technician as a result of the rest is calculated on the basis of how much time the technician has worked and the rest duration. Rest subtasks cannot be failed. None of the other variables active in a "normal action" subtask are involved in a rest calculation. At the conclusion of a rest subtask, both the perceptual-motor and the intellective ability of the simulated maintainers are augmented as a function of the fatigue relief induced by the rest.

3.4 Model Output

The MAPPS model provides information at varying degrees of granularity. The user may request information in one, several, or all of the following categories: subtask results (first iteration only), shift results, iteration results (first five iterations only), and run (task) summary.

- *Subtask* — information about each subtask, each time it is simulated during the first iteration.
- *Shift* — summary information about the simulation of an iteration or run from the beginning of the task to the point at which personnel were changed. This information is given for each shift change.
- *Iteration* — summarized information for the first five iterations of a run.
- *Run (task)* — summarized information for multiple simulations (iterations) of a task.

The detailed content of each type of simulation output is presented in Table 3.3.

3.5 Summary

Table 3.4 summarizes some of the principal interactions within the MAPPS model. The table attempts to show the major input variables, the internal model variables with which the input interacts, and the output which is affected by the interaction. The first column of the table can be read vertically for a listing of the input variables, and the table can be read horizontally for each variable, their internal interactions, and their affect on the output. For example, the input temperature interacts within the model with the ability level of the simulated work group to effect stress, the success or failure determination of the outcome of subtask performance, the number of errors committed, and task completion time. Of course, within an actual simulation, the success or failure of a simulated team on one subtask will affect the performance of subsequent subtasks. This type of effect is not included in Table 3.4. Moreover, the effects of branching and looping, emergencies, rest, and performance of special subtasks are not shown. However, the table serves to provide a partial structural integration and functional summary description of some of the major logic embedded in MAPPS.

Table 3.3. Detail of Content of Each Gutput Type

	Output Type			
Output	Subtask	Shift	Iteration	Run (Task) Summary
General Information				
Subtask Number	X		X	X
Subtask Type Number	X			
Subtask Description	X		X	X
Task Number		X	X	X
Task Description		X	X	X
Iteration Number			X	X
Number of Iterations				X
Shift Number		X		
Reason for Shift Change		X		
Run Identifier			X	X
Run Date			X	X
Source of Task Analysis				X
Subtask Performance				
Attempts	X		X	X
Outcome-Success	X		X	X
Outcome-Detected Error	X		X	X
Outcome-Undetected Error	X		X	X
Outcome-False Alarm	X		X	X
Outcome-Ignore	X		X	X
Probability of Success	X		X	X
Start Time	X			
End Time	X	X	X	X
Work Duration	X		X	X
Wait Duration	X			
Accessibility Effect	X			
Procedures Effect	X			
Last Subtask Performed		X	X	X
Task Performance				
Outcome			X	X
Performance			X	X
Effectiveness			X	X
Error Detection Ratio			X	X
Duration			X	X
Productivity			X	X
Error Consequence Index			X	X
Duration			X	X
Time Overrun/Underrun			X	X
Time Spent in Repeats			X	X
Emergency Duration			X	X
Subtask Preceding Emergency			X	X
Personnel Characteristics				
Ability Level-Intellective	X		X	X
Ability Level-Perceptual-motor	X		X	X
Ability Difference-Intellective	X			
Ability Difference-Perceptual-motor	X			
Ability Difference Effect	X			
Fatigue Effect-Intellective	X			
Fatigue Effect-Perceptual-motor	X			
Heat Effect-Intellective	X			
Heat Effect-Perceptual-motor	X			
Pace Adjustment Factor	X			
Time Stress	X		X	X
Communication Stress	X			
Total Stress	X		X	X
Maximum Total Stress			X	X
Subtask with Maximum Stress			X	X
End Total Stress		X	X	X
Number of Maintainers	X			
Personnel Ratio	X			

Table 3.3. Continued

	Output Type			
Output	Subtask	Shift	Iteration	Run (Task) Summary
Characteristics by Maintainer Type				
Type			X	X
Number			X	X
Work Time			X	X
Wait Time			X	X
Rest Time			X	X
Outcome-Successes			X	X
Outcome-Detected Errors			X	X
Outcome-Undetected Errors			X	X
Outcome-False Alarms			X	X
Outcome-Ignores			X	X
Personnel Shift Change Information				
Maintainer Type		X		
Personnel Replaced		X		
End Ability Level-Intellective		X		
End Ability Level-Perceptual-motor		X		
Radiation Absorption		X		
Time on Task		X		

Table 3.4. Summary of Major Input, Principal Interactions, and Effects of Interactions

Input Variable	Internal Interaction	Output Effect
Workplace		
Temperature	Abilities	S,O,E,T
Radiation	Stress	O,E,T
Noise	Stress	O,E,T
Maintainers		
Fatigue	Abilities	S,O,E,T
Intellective Ability	Ability Requirements	S,O,E,T
Perceptual-Motor Ability	Ability Requirements	S,O,E,T
Time Since Last Performance	Abilities	S,O,E,T
Supervisor's Acceptance	Success Probability	O,E
Stress Threshold	Stress	O,E,T
Overmanning	Stress	O,E,T
Motivational		
Maintainer Aspiration	Workpace, Aspiration	T
Supervisor Aspiration	Success Probability	O,E
Organizational Climate	Probability of Error Detection	O,E
Human Factors		
Accessibility	Ability Requirements	S,O,E,T
Protective Clothing	Ability Requirements	S,O,E,T
Procedures Quality	Ability Requirements	S,O,E,T
Subtask Requirements		
Intellective Ability	Ability Requirements	S,O,E,T
Perceptual-Motor Ability	Ability Requirements	S,O,E,T
Communication	Stress	E,T
Essentiality	Subtask Ignore	O
Task		
Time Limit	Stress	O,E,T
Time Limit Importance	Stress	O,E,T

S = Stress; O = Subtask Outcome (Success/Failure); E = Errors; T = Time

4. MAPPS MODEL COMPUTER PROCESSING

Chapter 4 provides a summary of the processing whch takes place within the computer program which represents the MAPPS computer model. More detailed descriptions of the computer program, including control menus, processing logic, and samples of output, can be found in Chapter 3 of Reference 1.

4.1 Computer Model Operation

The processing begins with the user logging on the terminal, and calling for the execution of the MAPPS program. The user is then presented with the main menu, a screen format from which choices may be specified and additional menus called. The user may request a local listing of any menu. Input data are entered or modified through these menus, as desired by the user. User requests for runs, output detail selection, and run identification are also made via the keyboard/terminal using menu selections. Control is transferred to the simulation portion of the MAPPS program after all input request information is entered and accepted. Error messages are presented to the user to indicate incorrect or invalid entries.

The simulation of a task consists of the simulation of subtasks beginning with the first subtask of the task. Each run of the model consists of a number of iterations (simulations) of the selected maintenance task.

Although nominally subtasks are simulated in numerical sequence, the model provides for repetition due to inadequate performance, branching within the subtask sequence, skipping subtasks due to work group decisions or time limitations, jumping in the subtask sequence, or looping back. For each subtask in the task, MAPPS selects the appropriate work group and manipulates data to simulate their performance of the subtask according to the logic of the model.

Figure 4.1 presents a summary of the processing within the model from a functional viewpoint. The computer program implementing this processing is written in FORTRAN IV H (enhanced) for the IBM 3033 system. The subsequent sections of this chapter describe the details of the processing as presented in Figure 4.1.

4.1.1 Log-On and Menu Entry

In order to implement the input, processing, and output logic, the MAPPS program was structured as a series of subroutines. Each subroutine performs a unique function.

The menu entry subroutine provides the user with an optional set of menus which allow entry of the conditions under which the simulated maintenance activity is performed and the type of output data to be provided. Eight such menus are available. Table 4.1 shows the general function of each menu.

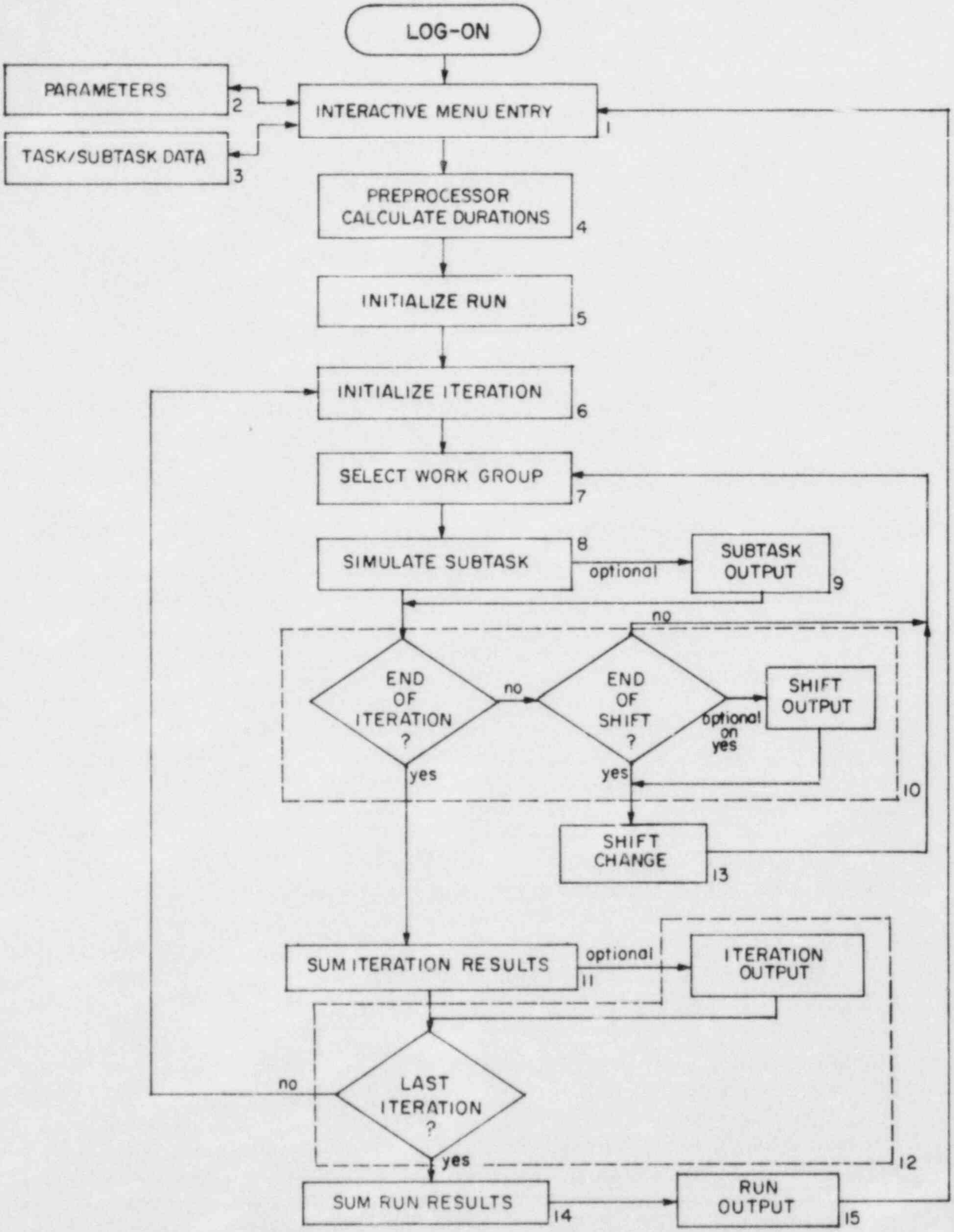

Fig. 4.1. Summary of MAPPS' Functional Processing.

Table 4.1. Function of Each MAPPS Menu

Menu No.	Name	Function
1	Initial	Provides seven execution options ranging from data entry to simulation execution and termination.
2	Output select	Provides for selection of output ranging from the most general (run (task) summary) to the most specific (subtask data).
6	Subtask duration	Automatically calculates average duration for each subtask when not provided as input.
7	Task Library	Allows inspection of details for up to 200 prestored tasks.
3A	Maintainer parameters	Allows variation of characteristics of each simulated maintainer; e.g., ability, prior radiation, stress threshold, level of aspiration.
3B	Task parameters	Allows variation of task features, e.g., radiation, temperature, time limit importance, noise level, procedures use probability.
4	Subtask data	Provides for update/modification/entry of task analytic data.
5	Task data	Allows update/modification/entry of total task data, e.g., shift change, shift change conditions.

4.1.2 Parameter and Task/Subtask Subroutines

The parameter and task/subtask subroutines control the user input information and provide default values whenever needed. These subroutines manage the processing and control of new information entered by the user relative to the task being simulated.

4.1.3 Preprocessor

Mean subtask completion time and the standard deviation of the mean are two input data requirements of the MAPPS model. However, such data are often not available in data banks or from observational data. Accordingly, a method was developed for estimating subtask performance time and standard deviation when such information is not available. The logic for this method is contained in the preprocessor subroutine. If all subtask durations and standard deviations are known, the preprocessor subroutine is not executed.

For the task to be simulated, the model user categorizes all subtasks of concern (i.e., those with unknown durations) into one of three duration groups, ranks the subtasks in each group in terms of duration, and enters the actual duration of the longest and the shortest subtask in each group. The program then, employing the longest and the shortest subtask duration values for each group, calculates the slope of the regression of rank on time using log transformed values for each group. The slope value is employed to calculate the mean performance time and its standard deviation for each subtask in the respective group.

Comparison of the output of the method with independent actual maintenance subtask performance time measures indicated very close correspondence between the actual time measures and the time estimates produced by the regression technique (Ref. 27).

4.1.4 Run Initialization

During the simulation of each subtask, MAPPS compares the current ability levels of the members of the simulated work group with the ability levels required for subtask completion. Two types of ability are considered: intellective and perceptual-motor. The level of each maintainer on each ability is based on input information. However, the MAPPS simulation assumes that, if a task is not performed over a period of time, a maintainer's performance proficiency on that task will degrade. MAPPS accomplishes the degradation due to nonrecent performance of a task by lowering the simulated ability levels of the technician(s) performing the task. The degradation is calculated in the run initialization subroutine as a function of the amount of time (and random effects) which has elapsed since the technician(s) last performed the task under consideration.

The run initialization subroutine also estimates the total radiation which each maintainer will accumulate during task performance by adding his prior exposure to his anticipated exposure during task performance. The total radiation is subsequently employed as a part of the stress calculation.

The quality of maintenance procedural aids (procedures, job aids) is another variable which MAPPS considers to affect task performance. The run initialization subroutine calculates the correlation between the quality of the maintenance procedures for each subtask in the total task and the essentiality of each subtask for total task completion. This value is subsequently employed in the simulation so that, everything else being equal, there is improved performance on tasks for which the maintenance procedures are of high quality for essential subtasks.

Additionally, the run initialization subroutine estimates the average time remaining for task completion at the conclusion of each subtask. These values are subsequently employed in the calculation of time stress which is one component of the total stress experienced by the simulated maintainers during the simulated performance.

Finally, the run initialization subroutine performs a number of control calculations largely related to shift changes, synchrony of personnel, and bookkeeping.

4.1.5 Iteration Initialization

During the course of a simulation, MAPPS dynamically adjusts maintainer abilities as a function of maintainer fatigue level and the temperature of the work place. Also, subtask ability requirements are adjusted as a function of the accessibility of the components involved in the maintenance activity under simulation, protective clothing requirements, and the quality of the maintenance procedures. The iteration initialization subroutine resets these and other adjusted values to their original levels at the start of each iteration.

MAPPS also allows for simulating the effects of assigned personnel being called away to participate in an emergency on the performance of the present maintenance task. When the input information indicates that an outside emergency event is to occur during the course of the performance of the current task, the iteration initialization subroutine randomly inserts the emergency into the subtask sequence and randomly assigns a time duration to the emergency. These values are subsequently employed to augment the fatigue level of the simulated maintainers who participate in the emergency and, accordingly, the performance of the maintenance task under consideration.

4.1.6 Select Work Group

The actual simulation within MAPPS is quite direct. The maintainers required for completing the initial subtask of the task are selected in the appropriate number and job specialties from the available personnel and their performance of the initial subtask are simulated. Then, the next subtask to be simulated is identified, work group members selected, and the performance of that subtask is simulated. This process continues until the performance of all subtasks in the task under consideration has been simulated. As stated earlier, branching, looping, and skipping of subtasks is permitted within the logic of the model. The work group selection subroutine selects the personnel to be assigned to the "performance" of the current subtask.

The selection is accomplished in terms of: (1) the required specialty (maintenance mechanic, electrician, instrument and control technician, supervisor, quality control,* control room operator*) mix of maintainers for subtask completion, (2) the number of maintainers in each job specialty required for subtask performance, (3) the number of maintainers available within each specialty, (4) the number of maintainers wearing protective clothing of the type required, and (5) the number required to be wearing these types of clothing. In case more maintainers are available than needed to be assigned, the maintainers who have worked least on the task under simulation are selected. If, in any specialty, fewer are available than needed, all available maintainers of the required specialty are selected.

The overmanning parameter enters the calculation in this subroutine. When overmanning is not permitted, as just described, MAPPS will make maintainer assignments up to the number of maintainers required. However, during a run for which input indicates that overmanning is permitted, all available maintainers up to twice the number of each type required will be assigned. Overmanning subsequently affects the time and quality of performance of the task under consideration.

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* Only *interactions* with these job specialties are simulated within MAPPS.

4.1.7 Simulate Subtask

Having selected the work group who will perform the next subtask to be simulated, the actual simulation of the work group's performance takes place. This simulation aspect essentially represents the core of MAPPS. The previous chapter was devoted to the discussion of this subroutine.

4.1.8 Shift Change

Following the simulation of each subtask, the program's flow depends on a series of checks regarding end of iteration and end of shift conditions. The end of iteration condition is satisfied when the simulated technician personnel have addressed the final subtask of a task. There are two methods of satisfying the end of shift condition. The user may indicate that personnel are replaced (shift change) based on a criterion of time into the task or completion of a specific subtask. Whenever either of these conditions is met, personnel changes occur.

The user may indicate up to 10 personnel changes. At each change, any number of maintainers may be replaced. The new personnel are assigned the same initial values of intellective and perceptual-motor ability, aspiration, etc., as the initial values of the personnel they have replaced. The variables which represent work time, wait time, and rest time are reset to reflect the status of the new technicians.

4.2 Model Output

The processing flow shown in Figure 4.1 indicates that following the end of shift and end of iteration determinations, the processing flows either to the select work group subroutine to simulate the next subtask or to the model output routines. The levels of output which are available to the user were described in Chapter 3. From the program operation point of view, following the generation and printing of the run output, the user may choose to terminate the simulation or he/she may choose to return to the initial menu and perform subsequent model runs.

5. DISCUSSION AND CONCLUSIONS

The preceding account of the MAPPS model and of the tests to which it was subjected suggest that the model is now ready for trial use. The results of the sensitivity tests reported in Chapter 4 of Reference 1 support a view that MAPPS behaves plausibly and exhibits appropriate sensitivity to changes in input variable levels. While neither all design options have been exercised, nor all model properties (e.g. practicality, acceptability, usefulness, validity) have been tested, at least a basic version of the analytic tool is ready and available. Chapter 5 presents the reasons that support confidence in the existing model.

5.1 Systematic Design

The design of MAPPS was derived from studies of "real world" nuclear power plant maintenance processes (Refs. 2,3,4,5,6) and of the technical literature pertaining to the variables inherent in these processes. The design process started with job analytic studies of the maintenance performed in a sample of nuclear power plants. From the obtained information, a descriptive model of the generalized nuclear power plant maintenance process was developed and reviewed. Concurrently, a survey of potential MAPPS users was conducted to determine the range of projected users and the features which these users considered to be desirable (Ref. 2). Applicable technical literature was also reviewed to establish, in conjunction with the job analyses and the prior experience in modeling of the developers of MAPPS, a set of operating variables to be considered. This literature review was continued with respect to each selected variable so as to determine its properties and behavior within the MAPPS model. Variables were then related to each other and the emergent structure was repetitively reviewed and refined.

5.2 Systematic Test of Design

The MAPPS design resulting from this systematic process seems to be a rational representation and approximation of the general nuclear power plant maintenance process. Tests of the model, as described in Reference 2, strongly support its sensitivity and plausibility. While empirical validation remains the ultimate criterion, together the design and test data appear to support contentions favoring the acceptability of the model.

For example Mayberry (Ref. 28) defined an acceptable model as one in which there is an earnest search for, and failure to find, a disqualifying defect. Disqualifying defects, as adopted from Mayberry's discussion, include at least the following:

1. *Symmetry* — If an entity is influential in the real world, it should be influential in the model.
2. *Continuity* — If the real world is continuous, the model's output should be continuous.

3. *Aggregation* — If two or more parameters are varied, the output should be different from the variation introduced by manipulating the parameters unitarily.
4. *Correct behavior in the limits* — If the model's output at the limits is not credible, the intermediate points may be suspect.
5. *Directionality* — 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 units* — If the units in the model do not reflect, at least within a monotonic transform, real world units, the model is suspect.

Table 5.1 presents an analysis of how each of these attributes is supported within the present development. Although a need for recalibration of some of the individual modules was revealed by the sensitivity tests, there were no disqualifying defects.

Future evaluation of the model will include aspects such as acceptability, practicality, and usefulness as well as empirical validity.

Table 5.1. Model Attributes and How Supported in MAPPS Development

Attributes	How Supported
Symmetry	Logic of and variables considered within the MAPPS are drawn from job analyses, literature, and prior modeling experience
Continuity	Sensitivity test results; see Ref. 1, Chapter 4
Aggregation	Sensitivity test results; see Ref. 1, Chapter 4
Correct Behavior in Limits	Sensitivity test results; see Ref. 1, Chapter 4
Directionality	Logic based on literature indications; sensitivity test results; see Ref. 1, Chapters 2 and 4
Physical Units	Real world physical units employed for physical variables; for other variables scaling procedures employed

5.3 Applications and Implications

The MAPPS model appears to be ready to assume a trial role as an analytic tool. While greater processing efficiency, increased convenience, and expanded features may be developed in the future, the present, initial version is ready to confer a new capability to its potential users. This new capability includes the availability of a technique for analyzing nuclear power plant maintenance from the point-of-view of human performance reliability. The technique is believed to provide, at least in part, the human performance information required for PRA analyses. The technique allows for the assessment of the tasks that maintenance technicians may perform in a less than satisfactory manner and what conditions or combination of conditions serve to contribute to or alleviate such performance. With such predictive information on hand, necessary corrective action can be taken before an incident occurs. The corrective action might take the form of regulations which serve to reduce the public risk associated with predicted nuclear power plant maintenance errors. Such regulations could encompass a variety of content areas addressed by the MAPPS model. These areas range from the conduct of maintenance through personnel training, selection, organizational policy, and plant design considerations.

Finally, there is reason to believe that a model which would provide information, similar to that provided by the MAPPS model, about nuclear power plant operators would represent a valuable tool for deriving needed information about plant operations. Such a model could be designed so that it runs interactively with the MAPPS model and/or as a stand alone model. Such computer simulation is within the current state-of-the-art and the potential for such simulation was demonstrated by the present work.

When human performance is considered, uncertainties exist about the dynamics of factors shaping that performance. "Deterministic" types of analyses are often poorly applicable to such nondeterministic situations. Neither the dynamic quantities nor the fundamental equations are certain. A model, such as MAPPS, is important because it allows an approximation of the real world and because it provides a context for developing and testing alternate perspectives into nondeterministic human involved situations.

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ORNL/TM-9041/V1
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NUREG/CR-3626, Vol. 1
ORNL/TM-9041/V1

2. *(Leave blank)*

3. RECIPIENT'S ACCESSION NO.

4. TITLE AND SUBTITLE *(Add Volume No., if appropriate)*
Maintenance Personnel Performance Simulation (MAPPS) Model: Summary Description

5. DATE REPORT COMPLETED
MONTH February YEAR 1984

7. AUTHOR(S)
Arthur I. Siegel, William D. Bartter, J. Jay Wolf, Helmut E. Knee, and Paul M. Haas

DATE REPORT ISSUED
MONTH May YEAR 1984

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Washington, D. C.

10. PROJECT/TASK/WORK UNIT NO.

11. FIN NO.
B0461

13. TYPE OF REPORT
NUREG/CR

PERIOD COVERED *(Inclusive dates)*

15. SUPPLEMENTARY NOTES

14. *(Leave blank)*

16. ABSTRACT *(200 words or less)*

A summary description is presented of the rationale for and the content and structure of the MAintenance Personnel Performance Simulation (MAPPS) model. The MAPPS model is a generalized stochastic computer simulation model developed to simulate the performance of maintenance personnel in nuclear power plants. The MAPPS model considers workplace, maintenance technician, motivation, human factors, and task-oriented variables to yield predictive information about the effects of these variables on successful maintenance task performance. MAPPS provides human performance reliability information pertinent to probabilistic risk assessment, regulatory decisions, and maintenance personnel requirements. The model, which is drawn from a firm research analytic base, was examined for disqualifying defects from a number of viewpoints and its sensitivity was extensively tested. The MAPPS model is believed to be ready for initial and controlled applications which are in conformity with its purposes.

17. KEY WORDS AND DOCUMENT ANALYSIS

17a. DESCRIPTORS

Nuclear Power Plant Maintenance
Maintenance
Human Reliability
Human Reliability Modeling
Modeling
Simulation Modeling
Monte-Carlo Simulation

17b. IDENTIFIERS/OPEN-ENDED TERMS

18. AVAILABILITY STATEMENT

19. SECURITY CLASS *(This report)*
Unclassified

20. SECURITY CLASS *(This page)*
Unclassified

21. NO. OF PAGES

22. PRICE
$

NRC FORM 335 (11 81)

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