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Maintenance Personnel Performance Simulation (MAPPS) - A Model for Predicting Maintenance Performance Reliability in Nuclear Power Plants*

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It has become increasingly recognized that human error contributes to the overall risk in the operation of nuclear power plants (NPPs). Human reliability is an integral part of assessment of man-machine interfaces including the many varied activities comprising the maintenance function. Human errors within maintenance tasks contribute to plant risk, and it is important to ensure that the diagnosis and improvement of maintenance performance reliability is carried out in a systematic manner.

The U.S. Nuclear Regulatory Commission (NRC) has recognized the utility of a structured methodology for providing quantitative maintenance personnel performance reliability data as input to probabilistic risk assessment (PRA) studies. Specifically, the NRC through the Oak Ridge National Laboratory (ORNL) in association with Applied Psychological Services, Inc. (APS), has developed a structured, quantitative, predictive methodology in the form of a computerized simulation model for assessing maintainer task performance. The primary objective of the overall program is to develop, validate, and disseminate a practical, useful, and acceptable methodology for the quantitative assessment of NPP maintenance personnel reliability.

Associated with defining the goals of this program was the recognition of several unique characteristics linked to the development of the methodology. First, because of the paucity of research directed toward the empirical evaluation of maintainer performance, the methodology to be developed would have to be minimally dependent on the availability and accessibility of data base information. Second, the development of such predictive methodologies, regardless of application, have historically suffered from insufficient validity evidence. Demonstration of validity was deemed essential for enhancing the acceptability of any methodology to be employed by the nuclear industry. Lastly, the methodology should be rich in output parameters to allow maximum applicability by users with varied performance informational needs.

The major objectives and activities comprising the program were organized into four program phases: (1) scoping study, (2) model development, (3) model evaluation, and (4) model dissemination. The program is currently nearing completion of Phase 2 - Model Development. Each of the phases will be subsequently discussed, major achievements will be highlighted, and the methodology will be described, and milestones yet to be accomplished will be noted.

Phase 1 - Scoping Study

The scoping study phase of this program had several general objectives. These were: (1) determine the informational data needs of potential users of the methodology, (2) determine generally the types of variables to include in a quantitative, predictive methodology, (3) examine existing human behavioral methodologies to suggest the type of methodology to be developed in this program, and (4) develop a comprehensive program plan for model development, evaluation and dissemination.

In order to meet objective one, a front-end user survey was conducted to assess the informational and analytic needs of potential users with regard to characteristics and capabilities of a computerized methodology. A formal user survey questionnaire was developed from results obtained from interviews with subject-matter experts from the NRC, NPPs, and architectural and engineering (AE) firms. Findings from the questionnaires suggested strong support for the utility of a computerized methodology.

Information relative to objective two came from job analyses of generic maintenance positions, two of which (maintenance mechanic[1] and supervisory position[2]) were accomplished during the scoping study, while the remaining two (instrument and control technician[3] and electrician[4]) were accomplished early in Phase 2. Information and data for the job analyses were obtained through the use of a formal questionnaire that was distributed to 27 nuclear power plants. Respondents were asked to supply ratings for the frequency of task performance, task completion times, perceived consequences of inadequate performance, and the amount of training required for a number of tasks in several task categories. In addition, for each task category, respondents were asked to indicate the amount of ability required, for 7 identified abilities, for successful task performance. The abilities addressed were: (1) visual speed, accuracy, and recognition, (2) gross motor control, (3) fine manual dexterity, (4) strength and stamina, (5) cognition, (6) memory, and (7) problem solving. The results of the job analyses provided a general attribute and ability profile of the various maintenance positions to support subsequent model development.

In conjunction with determining the general content of the model via the front-end user survey and the job analyses, a literature review of quantitative human behavioral methodologies was also accomplished. This review identified two generally applicable, whole-task methodology types (analytic and simulation) and examined several techniques in each category with respect to various desirable characteristics, some of which were also pointed out during the conduct of the front-end user survey. The characteristics looked for were: (1) generality (i.e., capable of modeling different job positions), (2) ability to handle interdependencies between task elements, (3) ability to emphasize human as well as equipment characteristics, (4) ability to supply output at various hierarchial levels (e.g., subtask and task levels), (5) ability to handle cognitive task elements, (6) capability for allowing sensitivity analyses to be carried out, (7) ability to utilize different data sources, and (8) ability to be used by non-specialists. Based on these characteristics as well as characteristics and features identified during the front-end user survey, computerized simulation modeling was suggested as the type of methodology to be developed in this program.

Following the selection of simulation modeling as the type of methodology to be developed in this program, a comprehensive program plan for the development, evaluation, and dissemination of the model was formulated. This plan along with a description of the front-end user survey and literature review was published in a front-end analysis report[5] following the completion of Phase 1.

Phase 2 - Model Development

This phase of the program involved the development, programming, and sensitivity testing of the model called, "MAintenance Personnel Performance Simulation (MAPPS)." MAPPS is a dynamic representation of human behavior and behavioral influences implemented on a digital computer so as to allow variation and prediction of a task or series of tasks. It will allow the analyst to vary the quality, quantity, type, and/or level of information input and processed in the representation and as a result, determine the effects of these variations on system output.

Early efforts during the development phase included the compilation of various applicable psycho-social theories, human behavioral and reliability theories and various existing models of human behavior. This information was then synthesized as needed for relevance to the maintenance context and incorporated into a simulation framework.

The MAPPS model is primarily an ability-driven model that operates on a subtask level. It compares the intellective and perceptual-motor abilities required for successful subtask accomplishment to the current maintainer abilities and subsequently derives an estimate of the probability of success for the subtask. The current abilities of the maintenance team are initial input ability levels, modified by various performance shaping factors such as stress, fatigue, heat, etc. Because of the inherent random variabilities and differences present between and in human beings, the effects of a given performance shaping factor on two essentially identical individuals may not be exactly the same. To account for this inherent variability, the MAPPS model establishes an upper and lower stochastic limit around the effects of the performance shaping factors and utilizes Monte Carlo sampling to choose a particular effect for a given individual. Due to the sampling in the model, a number of iterations of the task must be performed in order to obtain statistically stable and representative measures of performance.

The MAPPS model has incorporated a number of features that allow the simulation of task performance to be as realistic as possible. It can account for the effects of waiting time or idle time on applicable maintainers. It can accommodate shift changes during task performance. It allows the skipping of non-essential subtasks when the time remaining is short. The model also allows emergency events to occur during the subtask sequence and accounts for emergency effects such as ability degradation and time stress on the maintainers.

MAPPS has a significant number of input parameters as illustrated in Table 1. Most of these data have default values which allow the simulation to proceed if required input is not entered. The diversity and richness of the model's input parameters makes it particularly useful for a wide range of user applications.

TABLE 1

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MAPPS INPUT DATA

GENERAL

NUMBER OF MAINTAINERS
TYPES OF MAINTAINERS
TIME SINCE LAST PERFORMED CURRENT TASK/MAINTAINER
STRESS THRESHOLD/MAINTAINER
PRIOR RADIATION/MAINTAINER
PRIOR WORK BEFORE THIS TASK/MAINTAINER
ASPIRATION LEVEL/MAINTAINER
PERCEPTUAL-MOTOR ABILITY/MAINTAINER
INTELLECTIVE ABILITY/MAINTAINER
TEMPERATURE
RADIATION LEVEL
TASK TIME LIMIT
TIME LIMIT IMPORTANCE
SUPERVISOR'S EXPECTATION
RISK WEIGHT
TASK ESSENTIALITY LIMIT
NOISE LEVEL
PROBABILITY OF TEAM'S USE OF PROCEDURES
QUALITY OF PROCEDURES
NUMBER OF ITERATIONS
DURATION OF EMERGENCIES
TASK NAME
TASK NUMBER
TYPE OF NPP
NUMBER OF SUBTASKS

SUBTASK

SUBTASK NUMBER
KIND OF SUBTASK
SUBTASK ESSENTIALITY
NEXT SUBTASK IF SUCCESSFUL
NEXT SUBTASK IF FAILURE
PROBABILITY OF ERROR DETECTION BY SUPERVISOR
PROBABILITY OF ERROR DETECTION BY WORK GROUP
IS THERE A QC CHECK FOR THIS SUBTASK
ACCESSIBILITY
AVERAGE SUBTASK SUCCESS PROBABILITY
WHICH SUBTASKS ARE PRECIDENT
MUST ALL MEMBERS OF WORK GROUP START SUBTASK
AVERAGE DURATION OF THE SUBTASK
STANDARD DEVIATION OF SUBTASK DURATION
COMMUNICATION IMPORTANCE
CAN SUBTASK BE RETRIED
IS SUBTASK OF HIGH/INTERMEDIATE/LOW DURATION
A RANK FOR EACH SUBTASK ACCORDING TO AVERAGE DURATION
TYPES AND NUMBER OF MAINTAINERS REQUIRED
WHICH MAINTAINER TYPES MUST DONN PROTECTIVE CLOTHING
TYPE OF PROTECTIVE CLOTHING (PARTIALLY OR FULLY SUITED)

SHIFT

THE NUMBER OF THE SHIFT CHANGE
MAINTAINERS REPLACED
THE SUBTASK NUMBER AT WHICH SHIFT CHANGE OCCURS, OR THE TIME THIS SHIFT CHANGE OCCURS

The general overall model logic flow is illustrated in Fig. 1. Following the input of data via interactive menus, the pre-processor calculates the average subtask duration times and standard deviations for any subtask entered without these data. The calculation of the average subtask duration time is a unique feature that allows MAPPS to be relatively free from dependence upon a data base of subtask performance data. At least two empirical subtask duration times are required for each of three duration categories (high, intermediate, and low). Also required is a ranking of the subtasks according to their relative duration times. Utilizing the six known duration times which are subject to a logarithmic transformation as anchors, MAPPS employs a linear regression technique to estimate the duration times of the ranked subtasks. Once these subtask duration times have been calculated they may be viewed by the user and modified (if desired) prior to initiating the simulation process (not shown on Fig. 1).

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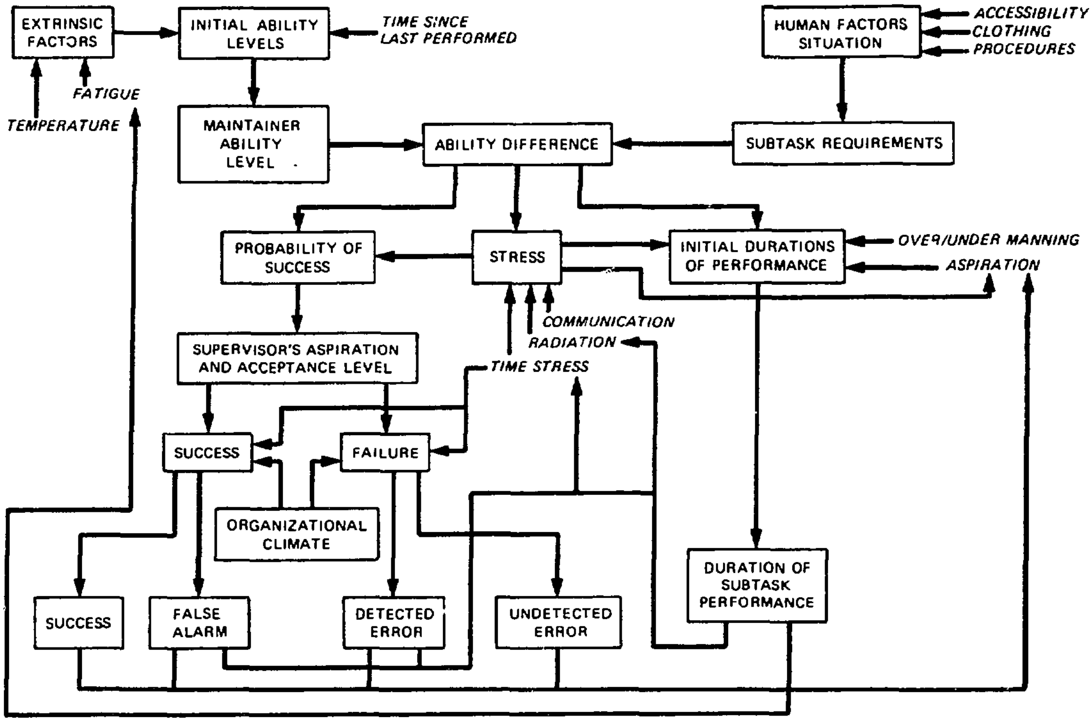

Figure 1. MAPPS model logic flow

Once an adequate set of average subtask duration times has been obtained, MAPPS initializes the run by degrading the abilities of the team members in proportion to the length of time since each maintainer last performed this task. In addition, it also calculates an initial level of stress for each maintainer dependent upon any prior radiation exposure and the expected dosage during task performance. Prior to starting the actual simulation, various constant task parameters are identified, such as: total time limit for task accomplishment, task essentiality and the quality of the maintenance procedures. After these have been identified, the first simulation (iteration) of the task is initiated by identifying the first subtask to be accomplished. For each subtask to be simulated, the model will select the required working group from the available team of up to eight maintainers. If the task is overmanned for a particular type of maintainer, the model chooses those with the least amount of time worked during the current shift. The maintainers not selected are either idle or may be selected for another subtask that can be accomplished concurrently with the subtask being considered. Upon completion of the selection of the team members, simulation of the subtask begins. The simulation module is the heart of the MAPPS model and is discussed later in this paper.

A number of outcomes are possible following the simulation of each subtask. These are:

(1) Success: The subtask was completed, no errors were committed and the team perceives the subtask to be successful.

(2) False Alarm: The subtask was completed, no errors were committed, however, the team perceives the subtask to be unsuccessful.

(3) Detected Error: The subtask was completed, error(s) were detected by the working group/supervisor/quality control inspection and the subtask is perceived as unsuccessful.

(4) Undetected Error: The subtask was completed, errors were committed but not detected. The subtask is perceived as successful.

In addition, the model will also allow the maintenance team to skip non-essential subtasks when the time remaining is short compared to the total time limit for task accomplishment. The non-essentiality of a subtask is determined by comparing the subtask essentiality (input data) to the task essentiality limit (also input data). When time is short, any subtask whose essentiality is below the task essentiality limit will be skipped.

The direction of the model is dependent upon the perceived success of the subtask by the maintainers. The input data indicates which subtask is to be performed next, dependent upon perceived success or failure of the current subtask. In most instances, the direction of the model following a perceived failure will be to retry the failed subtask. Up to two additional entries are allowed by the model.

At the completion of the simulation of a subtask, the model checks to see if a shift change has been called for. If so, the model replaces personnel with similar personnel who have not had prior work on the shift. In effect, the replacement individuals are exact copies of the individuals being replaced except that they are fully rested. Once shift changes have been accommodated, the model moves to the next subtask, selects the appropriate work group and proceeds to simulate the new subtask as previously described. When all subtasks have been simulated (a maximum of 100 subtasks per task), one iteration has been completed. The model allows up to 100 iterations, with ten being the default value. Each subsequent iteration begins by re-initializing all model variables to their pre-simulation state. Each iteration is independent of all others. For a given iteration, a task is labeled as a success if all attempted subtasks have been successfully completed prior to the task time limit.

A significant amount of output data is available at four different levels of hierarchical output (subtask, shift, iteration and run levels). Selected MAPPS output data are listed in Table 2. Unless otherwise requested by the user, only output at the run level will be automatically generated.

As mentioned earlier, the simulation module is the heart of the MAPPS model. The overall logic flow of the simulation module, illustrated in Fig. 2, is utilized to simulate each applicable subtask. Prior to the simulation of the first subtask, each maintainer has determined intellective and perceptual-motor abilities based upon an initial input of these abilities, time since each maintainer last performed this task and a stress

TABLE 2

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SELECTED MAPPS OUTPUT DATA

SUBTASK PERFORMANCE

- NUMBER OF ATTEMPTS
- NUMBER OF SUCCESSES
- NUMBER OF DETECTED ERRORS
- NUMBER OF FALSE ALARMS
- NUMBER OF IGNORES
- PROBABILITY OF SUCCESS
- START TIME
- END TIME
- WORK DURATION
- WAIT DURATION
- ACCESSIBILITY EFFECT
- PROCEDURES EFFECT

TASK PERFORMANCE

- OUTCOME
- PERFORMANCE
- EFFECTIVENESS
- ERROR DETECTION RATIO
- PRODUCTIVITY
- ERROR CONSEQUENCE INDEX
- DURATION
- TIME OVERRUN/UNDERRUN
- TIME SPENT IN REPEATS
- EMERGENCY DURATION

TEAM CHARACTERISTICS

- INTELLECTIVE ABILITY LEVEL
- PERCEPTUAL-MOTOR ABILITY LEVEL
- INTELLECTIVE ABILITY DIFFERENCE
- PERCEPTUAL-MOTOR ABILITY DIFFERENCE
- ABILITY DIFFERENCE EFFECT
- FATIGUE EFFECT - INTELLECTIVE
- FATIGUE EFFECT - PERCEPTUAL MOTOR
- HEAT EFFECT - INTELLECTIVE
- HEAT EFFECT - PERCEPTUAL MOTOR
- TIME STRESS
- COMMUNICATION STRESS
- TOTAL STRESS
- MAXIMUM TOTAL STRESS
- SUBTASK WITH MAXIMUM STRESS

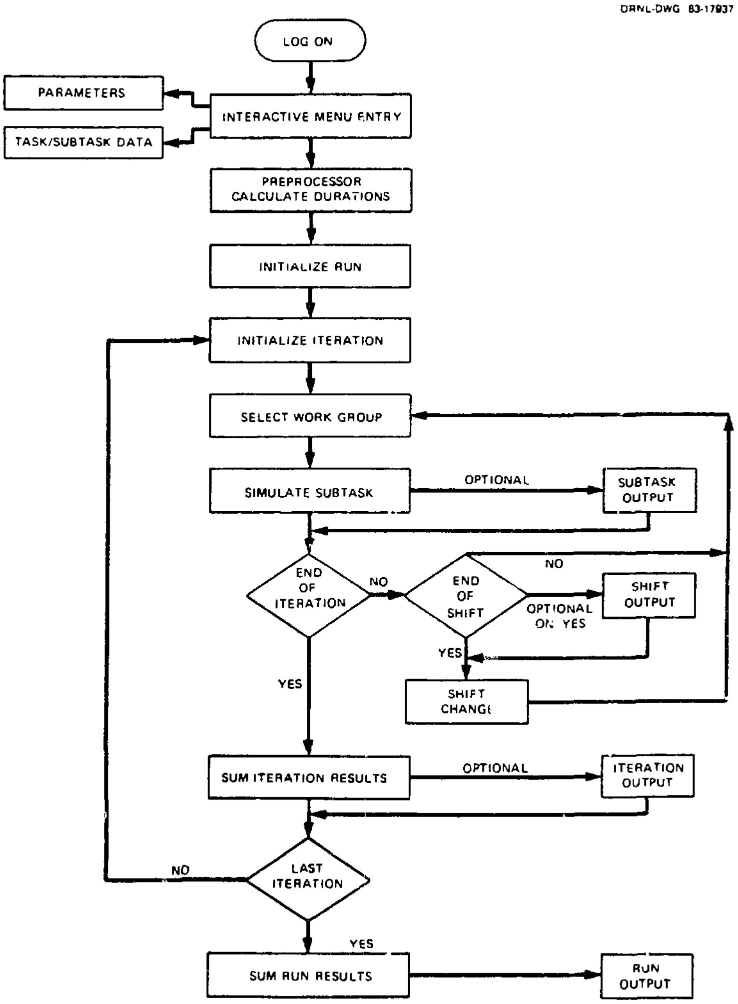

Figure 2. Logic flow of simulation module

level which is a function of any prior radiation absorbed and the expected dosage during task performance. For each subtask, the abilities of the maintainers are further degraded by their fatigue level and the temperature of the work area. In addition, each subtask to be simulated has associated with it a set of variables describing the human factors situation. These are the degrees of visual and physical accessibilities, the need for and types of protective clothing and the quality and expected use of procedures. The model then determines the subtask ability requirements from the factors involved in the human factors situation.

The difference between the current ability levels (intellective and perceptual-motor) of the team and the ability requirements of the subtask is the principal variable around which the simulation module was developed. The team's ability differences have a direct impact on three other principal variables which are: the team's total stress, the duration of subtask performance, and the probability of subtask success.

The total stress of the team is composed of four parts: the stress stemming from the ability differences for this subtask (ability difference stress), the stress stemming from the proximity of the team's total absorbed radiation to the radiation absorption limit (radiation stress), the stress stemming from the need for communication during subtask performance (communication stress), and the stress stemming from the nearness of any time limits for task performance (time stress). The value of the total stress directly affects the duration of subtask performance and the probability of success.

The duration of subtask performance is calculated by modifying the input or previously calculated average subtask duration time by several factors: the team's ability differences, the team's total stress, the team's aspiration level and the manning situation (overmanned-undermanned). The aspiration level and total stress calculated are assumed to be constant for the current subtask and are incremented only at its conclusion, prior to the simulation of the next subtask.

The probability of subtask success is dependent upon the team's ability differences and the team's total stress. It is used in conjunction with the supervisor's aspiration level, his acceptance level of the work being performed, the team's time stress and an organizational climate variable (an overall measure of a number of factors including job satisfaction, organizational structure, quality of work conditions, etc.) to determine the outcome of subtask performance.

When the subtask duration time and outcome have been determined, the simulation of the current subtask has been completed and the model proceeds to the next applicable subtask. Before its simulation, the model updates the team's fatigue level, aspiration level, radiation stress level and time stress level depending on the performance of the previous subtask. If subtask simulation was unsuccessful and the subtask is retried, the retry is treated as a new subtask with time dependent variables modified accordingly.

The MAPPS model is being developed primarily to produce overall task performance measures based on the simulation at the subtask level. From the input received from the job analyses of the various maintenance positions, and from preliminary task analyses accomplished for several maintenance tasks, it was evident that several special types of subtasks would be encountered. These subtasks address rest time, donning of protective clothing, doffing of protective clothing, troubleshooting and decision making. The MAPPS model is being developed to account for these special types of subtasks.

As part of the model development phase, MAPPS will be debugged, sensitivity tested and calibrated. Task analysis data for several selected maintenance tasks will be utilized to run a number of cases in which input variables are systematically varied. The purpose of these runs will be to aid in debugging the programmed model and to demonstrate the reasonableness of the model output. Task iterations will also be examined to assess the stability of the model. The model will be calibrated as needed and subsequent runs accomplished to ensure the reasonableness of output. Upon completion of sensitivity testing, the model will be considered fixed for validation purposes. Sensitivity testing is expected to be completed by the end of calendar year 1983, and a limited release to the NRC will be made.

Phase 3 -- Model Evaluation

In general, the development of human behavioral models have historically been accomplished without the benefit of evidence of validity. Often times this was attributed to potentially high costs or severe hazards associated with the nature of the situation being simulated. Adequate evidence of validity however is not only an important aspect of empirically assessing the value of a given model, but it would also tend to strengthen its acceptability. For these reasons, a comprehensive effort will be aimed toward validation of the MAPPS model.

A number of considerations will be addressed in planning the model validation. These include the availability and accessibility of data sources and the selection of specific validation tasks. The overall focus of this phase is to collect and evaluate performance data for comparison to model predictions. Such analyses build evidence supportive of different types of validity. Specifically, construct validity deals with the internal relationship among the model's modules and with model output, i.e., a consistency of relations conforming to recognized theories and performance data. Criterion validity is assessed by the efficacy of the model in simulating criterion performance profiles using feasible and acceptable data sources. Content validity refers to adequacy of the contents of the model, i.e., the modules and parameters, in reflecting important variables determining or influencing actual maintainer performance. Evidence of content validity has already been accrued through the front-end user survey in which subject-matter experts identified factors related to human reliability and through a formal peer review of the model contents.

Validation Procedures

Several sources of maintainer performance data will be considered for use in assessing the model's criterion validity. These include: real-time observation of maintenance teams performing selected tasks, walk- and/or talk-throughs of tasks with supervisors and maintainers, maintenance simulators, and consensus-seeking approaches utilizing subject-matter experts. In addition to collection of maintainer performance data, task analysis data will be compiled conforming to the model's subtask input requirements.

Following data collection, statistical analyses of the information will be conducted. Task analytic and performance data will be input to the simulation model and predicted outcomes will be generated. These predictions will be statistically compared with collected field data and tested for similarities and differences. Analyses will address model internal validity by assessing correlations among modules and model output, as well as external validity in correlations among actual and predicted task outcomes. Results will be evaluated using the criteria of acceptability, practicality, and usefulness to formulate overall findings across all validation designs and analyses. Following the completion of the validation phase, the MAPPS model will be released to the NRC and the public. This general release is tentatively scheduled for the end of calendar year 1984.

Phase 4 -- Model Dissemination

Following the general release of the model, the project team will design and implement a comprehensive workshop to effectively transfer the MAPPS methodology to its potential users. The workshops will allow potential users to gain "hands-on" experience in use of the MAPPS model and will emphasize its proper application and effective utilization. One or more workshops will be conducted as needed, starting about mid-fiscal year 1985.

Summary and Conclusions

The MAPPS model is being developed primarily to provide maintainer reliability data in support of PRA studies. Because of the richness of both the types of input and output parameters addressed, the model may also prove to be a valuable source of information for areas such as system design evaluation, maintenance operations analysis, and a human factors data store.

The MAPPS model is currently near the completion of the development phase and efforts to demonstrate its validity will be initiated early in calendar year 1984. Evidence of validity will be collected from feasible and acceptable data sources and will be compared to results generated by the model. Throughout the evaluation phase, efforts of demonstrating the model's practicality, usefulness and acceptability will be emphasized. The general release of the model is tentatively scheduled for early in calendar year 1985.

Upon the general release of the model, workshops will be conducted for potential users to ensure its proper application and effective utilization.

The development and subsequent validation of the MAPPS model will be a significant step toward providing a valuable source of NPP maintainer reliability data for PRA studies as well as system design evaluation, maintenance operations analysis and a human factors data store.

References

1. A. I. Siegel, W. D. Bartter, and F. E. Kopstein, "Job Analysis of the Maintenance Mechanic Position for the Nuclear Power Plant Maintenance Personnel Reliability Model," NUREG/CR-2670, ORNL/TM-8301 (June 1982).

2. W. D. Bartter, A. I. Siegel, P. J. Federman, "Job Analysis of the Maintenance Supervisor and Instrument and Control Supervisor Position for the Nuclear Power Plant Maintenance Personnel Reliability Model," NUREG/CR-2668, ORNL/TM-8299 (November 1982).

3. A. I. Siegel, W. D. Bartter, P. J. Federman, "Job Analysis of the Instrument and Control Technician Position for the Nuclear Power Plant Maintenance Personnel Reliability Model," NUREG/CR-3274, ORNL/TM-8754 (to be published - September 1983).

4. P. J. Federman, W. D. Bartter, A. I. Siegel, "Job Analysis of the Electrician Position for the Nuclear Power Plant Maintenance Personnel Reliability Model," NUREG/CR-3275, ORNL/TM-8755 (to be published - November 1983).

5. A. I. Siegel, W. D. Bartter, J. J. Wolf, H. E. Knee, and P. M. Haas, "Front-End Analysis for the Nuclear Power Plant Maintenance Personnel Reliability Model," NUREG/CR-2669, ORNL/TM-8300 (August 1983).