CONF-841099--6

The Maintenance Personnel Performance Simulation (MAPPS) Model*

Arthur I. Siegel
William D. Bartter
J. J. Wolf

Applied Psychological Services, Inc.
Wayne, Pennsylvania 19087

CONF-841099--6

DE85 002324

Helmut E. Knee
Paul M. Haas

Oak Ridge National Laboratory**
Oak Ridge, Tennessee 37830

Human Factors Society 28th Annual Meeting on New Frontiers for Science and Technology, San Antonio, Texas, October 22-26, 1984

*Research sponsored by the Nuclear Regulatory Commission.

**Operated by Martin Marietta Energy Systems, Inc. under Contract #DE-AC05-84OR21400 with the U.S. Department of Energy.

THE MAINTENANCE PERSONNEL PERFORMANCE SIMULATION (MAPPS) MODEL

Arthur I. Siegel
William D. Bartter
J.J. Wolf

Applied Psychological Services, Inc.
Wayne, Pennsylvania 19087

Helmut E. Knee
Paul M. Haas

Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

ABSTRACT

A stochastic computer model for simulating the actions and behavior of nuclear power plant maintenance personnel is described. The model considers personnel, environmental, and motivational variables to yield predictions of maintenance performance quality and time to perform. The model has been fully developed and sensitivity tested. Additional evaluation of the model is now taking place.

Digital computer based simulation modeling has become an accepted technique for modeling systems in order that predictions can be made about how well a system will function and why it will function at the anticipated level. Such information is of primary interest to engineers and scientists concerned with system planning, design, and evaluation.

The Maintenance Personnel Performance Simulation (MAPPS) model was developed to provide such insights relative to nuclear power plant maintenance. A principal focus of the model is the generation of maintenance oriented human performance reliability data for probabilistic risk assessment purposes.

Background for the MAPPS Model

Simulation model development depends on a full understanding of the tasks to be modeled and the conditions of task performance along with an understanding of the requirements of the model user. The former understanding is required in order that the model will realistically reflect the nuances, exigencies, and conditions of the situation modeled. The latter understanding is important in order that a practical, acceptable, and useful tool be provided to the ultimate user of the model.

The development of the MAPPS model was based on the firm foundation provided by: a front-end analysis and four job analyses. The front-end analysis (Siegel, et al. 1983) 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 about 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 the maintenance mechanic (Siegel et al., 1982), the instrument and control technician (Siegel et al., 1983), electrician (Federman et al., 1983), and supervisor (Bartter et al., 1982) 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, training time and 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.

Specific Purpose of the MAPPS Model

The specific purpose of the MAPPS model is to allow quantitative analysis of the effects of varying a set of maintenance 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 the maintenance task under consideration.

Simulation Content

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. 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 presented later and fully elaborated in Siegel et al. (1984, 1984a). Within the logic, the following concepts are included during the simulation of each subtask: difference between the intellective and the perceptual-motor ability 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 level of aspiration, quality of written procedures for supporting performance, supervisor's expectancy about the quality of performance, accessibility, wearing protective clothing, time since the various team members last 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 stochastic features to account for intra- and interindividual, situational, and contextual differences.

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, and in the case of subtask failure, to repeat the simulation of the subtask, loop ahead or back in the subtask sequence, or branch into a new subtask sequence.

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

Processing Detail

The processing within the MAPPS model is based on the 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.

Figure 1 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).

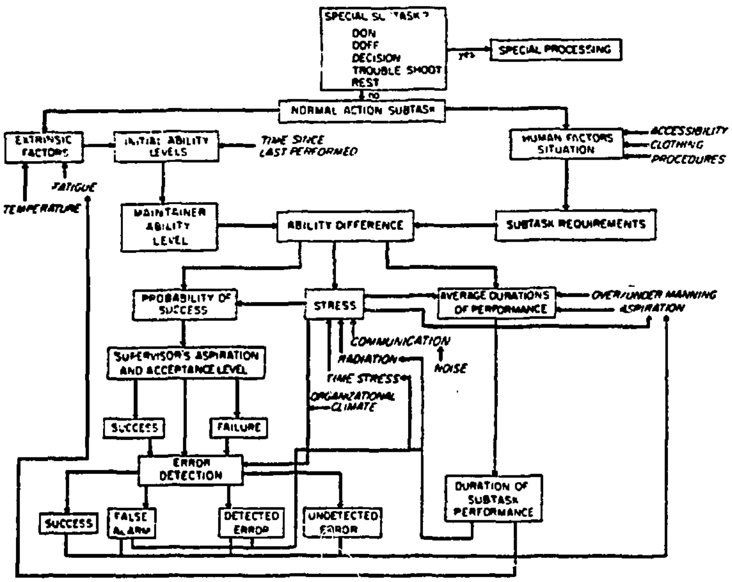

Figure 1. Overview of logic flow within MAPPS model.

Within the flow logic, the following considerations are implemented:

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 simulated maintainer(s). 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.

2. Stress on the simulated 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°F, 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 workgroup'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 any conditions which fail to support communication.

11. If a task is overmanned, performance time will appropriately decrease.

12. Depending on whether or not the stress level is above the stress thresholds of the maintainers and whether or not the difference between the simulated maintainers' levels 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.

In addition to normal action subtask processing logic, the model possesses special logic to simulate the performance of trouble-shooting decision making, rest, and protective garment donning and doffing.

Model Output

The MAPPS model provides the user with a wide variety of human performance reliability oriented information. This includes quantitative data about technician performance, areas of success and failure, performance time, detected errors, undetected errors, and stress when input parameters are varied. Such information is useful for a wide variety of personnel planning and task structuring situations.

Sensitivity Test of MAPPS

After its initial development, the MAPPS model was subjected to a broad set of sensitivity tests to assess the reasonableness of the effects of input variation on the output of the model.

Table 1 presents a partial listing of the model sensitivity tests which were completed along with a qualitative description of the results obtained relative to selected performance indices. The arrows in Table 1 indicate the directionality of performance change as indicated by MAPPS. Fuller detail about the results of these tests is presented in Siegel et al. (1984a). In almost all instances,the obtained directionality of effect was in concordance with expectation.

Model Evaluation

An extensive evaluation of the MAPPS model is currently being performed. The evaluation considers empirical model validity issues as well as model practicality, acceptability, and usefulness. Empirical model validity issues include predictive validity estimates and internal validity determinations on the basis of causal analytic and correlational methods. Model practicality includes such issues as the cost of ownership, personnel and training requirements, portability, compatability, and model operating requirements. Model acceptability refers to the reaction to the model of potential users, including risk assessment analysts, the Nuclear Regulatory Commission, and utilities personnel. Model usefulness includes such considerations as completeness, robustness, and expandability.

Conclusions and Implications

The results of the sensitivity tests and of model runs completed to date indicated that a model has been developed which will provide useful information for a number of personnel, human factors, and regulatory decisions relative to nuclear power plant maintenance. The MAPPS model appears ready to assume a trial role as an analytic and diagnostic tool and it is anticipated that the results of such use will confer a new capability to its 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 and, as a result, providing the insights necessary for improving maintenance capability.

Table 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.

REFERENCES

Bartter, W.D., Siegel, A.I., and Federman, P.J. Job analysis of the maintenance supervisor and the instrument and control supervisor position for the nuclear power plant maintenance personnel reliability model. Oak Ridge: Oak Ridge National Laboratory. NUREG/CR-2668, 1982.

Federman, P.J., Bartter, W.D., and Siegel, A.I. Job analysis of the electrician position for the nuclear power plant maintenance personnel reliability model. Oak Ridge: Oak Ridge National Laboratory, NUREG/CR-3275, 1983.

Siegel, A.I., Bartter, W.D., and Federman, P.J. Job analysis for instrument and control technician position for the nuclear power plant maintenance personnel reliability model. Oak Ridge: Oak Ridge National Laboratory, NUREG/CR-3274, 1983.

Siegel, A.I., Bartter, W.D., and Kopstein, F.F. Job analysis for maintenance mechanic position for the nuclear power plant maintenance reliability model. Oak Ridge: Oak Ridge National Laboratory, NUREG/CR-2670, 1982.

Siegel, A.I., Bartter, W.D., Wolf, J.J., Knee, H.E., and Haas, P.M. Front-end analysis for the nuclear power plant maintenance reliability model. Oak Ridge: Oak Ridge National Laboratory, NUREG/CR-2669, 1983.

Siegel, A.I., Bartter, W.D., Wolf, J.J., Knee, H.E., and Haas, P.M. Maintenance personnel performance simulation model (MAPPS): Summary description. Oak Ridge: Oak Ridge National Laboratory, NUREG/CR-3626, Vol. 1, 1984.

Siegel, A.I., Bartter, W.D., Wolf, J.J., Knee, H.E., and Haas, P.M. Maintenance personnel performance simulation model (MAPPS): Description of model content, structure, and sensitivity testing. Oak Ridge: Oak Ridge National Laboratory, NUREG/CR-3626, Vol. 2, 1984a.

1. This work was completed under subcontract 62X-70527 between Applied Psychological Services and the Oak Ridge National Laboratory. We are indebted to T. Ryan and others at the Nuclear Regulatory Commission for their advice and comments throughout the work.