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COMPUTERIZED MEASUREMENT OF OPERATOR PERFORMANCE ON SIMULATORS

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This computer-based system aids in evaluating operator's performance on a power plant simulator. The Performance Measurement System (PMS) helps the instructor in his total evaluation by providing objective measurements and documentation of operator reaction time, sequence of manipulation, and extent of parametric control. These measurements can also apply to Human Factors research on the operator-control room interface.

1. INTRODUCTION

A computer based evaluation system has been developed for objectively measuring certain elements of an operator's performance on a power plant simulator. The system is designed to help the instructor in his total evaluation by providing measurements and documentation of certain essential elements of a trainee's performance. Some measurements of operator performance can apply to Human Factors research on operator - control room interfacing.

This Performance Measurement System (PMS) was developed by General Physics Corporation, working under an Electric Power Research Institute (EPRI) contract (EPRI-NP-783). The data produced by the system can be utilized for training evaluation and for research. In providing an empirical data base for statistical analyses of trainee performance, the system offers capabilities for measuring operator reliability in an operational plant. There are additional applications of the system. Allocation of safety and control functions between operators and automated controls can also be more objectively determined. Further, the system presents a method for improving evaluations of the effectiveness of control room designs and operating procedures.

In the first project phase, a team designed, installed and completed test runs on the TVA Browns Ferry nuclear power plant training simulator. The Performance Measurement System showed itself highly capable of automatically recording statistical information on operator actions and plant responses. Key plant variables and operator actions were monitored and analyzed by the simulator computer for both normal operating and casualty drills.

The computerized system provided measurements of how the operator had responded to plant indicators and made switch manipulations. Data collected and evaluated was on all the control room gauges, annunciator lights, and switch and knob positions. The pilot exercises on the Browns Ferry simulator (BWR-GE) measured performance parameters on reactor criticality, plant startup, scram from high power, and Main Steam Isolation Valve (MSIV) closure. In the current phase of the project, ten scenarios on three power plant simulators have been developed for PMS evaluation.

2. PROGRAMMING APPROACHES

The simulator computer consists of three functional blocks: the direct memory access Input/Output (I/O) section, the central processing unit, and the main memory. The direct memory access I/O section is a communications link between the computer and various input and output devices. An example of an input is the operator's closing a switch in the course of the exercise. Examples of output devices on the simulator are the control room meters that are being driven by the computer simulation programs, and valve position-indicating lights on the control panel. The main memory stores programs and data. The central processing unit provides sequencing and timing for processing instructions, and controls the data paths between various parts of the computer.

Without significant hardware additions, real time processing greatly limited the amount of data that could be collected for research needs and required the data to be clearly identified before the assembly language programming effort; therefore, real time processing could not be used. Real time data/off-line process was selected using "off-line processing" FORTRAN programs for training and research. The overwhelming majority of the programming is in FORTRAN. These programs could be readily adapted to other simulators.

After the "real time data/off-line processing" approach was selected, the system was designed to use the existing hardware of the Browns Ferry (BWR), Sequoyah (PWR), and Cumberland (Fossil) simulators at the Tennessee Valley Authority Training Center.

3. DATA COLLECTION

During the conduct of a simulator exercise, all control room data (gauges, annunciator lights, switch and knob positions) is collected on magnetic tape. The taped data is evaluated later on other computers.

The simulation programs have four types of inputs and outputs as follows:

- Digital Inputs -- discrete inputs from the control room to the simulation programs. An example is the position of a two-position switch on one of the control panels.
- Digital Outputs -- discrete outputs from the simulation programs to the control room. An example is the signal to an annunciator light, turning it "on" or "off."
- Analog Input -- continuous inputs from the control room to the simulation programs. An example is the position of a control knob on one of the control panels.
- Analog Output -- continuous output from the simulation programs to the control room. An example is a meter reading on one of the control panels.

Simulator data, consisting of the above types of inputs and outputs, is collected by a data collection program and stored on magnetic tape. This occurs concurrently with the normal operation of the simulator (i.e., "on-line"). The data collection program is added to the basic simulation program to accomplish this data collection.

For the development of the Performance Measurement System, it was decided to collect all I/O information once per second. Switch manipulations are checked at 1/4 second intervals to avoid missing a rapid manual action by the operator, but the record of those actions comes out only once per second. To extend data collection time available, a dynamic compression technique was developed to reduce data bulk. Basically stated, if no changes occur, no data is collected. When any change occurs, a data record containing the time is written. The resulting data is a sequence of "snap-shots" of the simulator, each containing the status of every light, meter, switch and knob on the simulator.

The data that is stored on tape is a binary representation of the information displayed in the control room. A switch position or an annunciator light's status is represented by a 1 or 0 in a specific bit of information. An analog read-out is represented by a 16-bit binary number representing a percentage of full scale for a meter reading or knob position. The data evaluation programs must therefore convert these binary numbers to their engineering units as the first step in the evaluation. A standard FORTRAN program can then be written to evaluate the converted data for the purpose of a research project.

4. EXERCISE DEVELOPMENT

The development of an exercise must start with a clearly defined idea of what plant evolutions are to be involved. The exercise must cover a discrete facet of plant operation suitable for evaluation and compatible with available initial conditions in the simulator. Ideally, the exercise will follow operating and emergency procedures with a single correct path of operator actions which delivers the plant in the desired condition (e.g., reactor startup). One must be alert for steps in which there are multiple paths to accomplish a given requirement. Those cases must be specifically noted in order to account for that variability of action in the programming. Consideration is given to:

- Operator Actions
- Controlled Variables
- Milestone Events
- Objective Errors Possible
- Subjective Checklist

The subjective checklist covers operator actions such as "check" or "verify" which cannot be documented on a data tape. Subjective evaluation of these aspects of operator performance by the instructor or researcher are still necessary.

5. PERFORMANCE

In order to measure "performance" it must somehow be quantified. The initial development of the Performance Measurement System was <u>error</u> oriented. The absence of errors was "good" performance. The exercise programs detect specifically defined errors in the operator's actions. Most fall into three categories:

1. Omission
2. Sequence
3. Limit Violations

The errors of <u>omission</u> and <u>sequence</u> relate to a progression of operator actions thru a procedure. <u>Limit Violations</u> are failures to control some parameter within proper bounds.

6. ERROR CLASSIFICATION

Using errors as a negative performance measure is easy if Operator A makes an error and Operator B doesn't. Then we say Operator A is better. But if both make some errors, the errors must be ranked by "badness" to determine the better performer. It is easy to get agreement that: "All errors are not equal!" but it is very difficult to get agreement in the relative ranking of errors. A major area of contention is the safety/economic conflict; which is worse?

To allow a classification of errors and avoid the safety vs. economics controversy, current efforts are to implement a multi-attribute scaling. In effect, the safety and economic considerations are separated, and a given error is ranked according to its consequences in each of several areas considered individually. The areas of consequence considered are:

(a) Safety

(b) Potential Safety

(c) Economic

(d) Potential Economic

(e) Personal

It will be seen that this "multi-attribute" method of categorization provides more information than a "single-attribute" method in which a given error must be placed along a single scale, relative to all other errors. The computer can search the error data for those errors which are at or above a certain level or another scale, etc.

Example - Error 13062:

A-1 Violation of Limiting Condition for Operation

B-3 Potential Safety Limit Violation

C-0 No Economic Consequences

D-6 Potential $1,000,000

E-2 Shift Supervisory Reprimand

7. CONTINUOUS VARIABLE CONTROL

One of many operator tasks is to control plant states in a stable manner as well as staying within operating limits. Certain continuous variables tend to reflect stability during manual operations; but absolute criteria for stable performance within technical specification limits are arguable. Operator smoothness and control strategy varies as does the opinions of raters. While most raters would agree on what constitutes highly unstable performance, quantification of the degree of smoothness is subjective. In this kind of situation the best approach to developing measurement is to find out what instructors, operators and trainees really do (i.e. how they control quantitatively). Given quantitative data, criteria can be derived for training performance assessment based on those measures (out of a variety of possible measures) which reveal the differences between experts and novices.

To evaluate operator performance in control of a continuous variable like Steam Generator Water-Level Control, analysis software was developed which produces time-history and "state space" outputs from a PMS data tape. The purpose is to reveal the control techniques or strategy which the operator uses in this complex control problem. The goal is to quantify performance, using these tools to allow recording and comparing operator performance on this problem. While the time-history printout illustrates the control problem (interrelating water level, feed flow, steam flow, reactor power level, and control activity), no coherent, quantitative measure of performance appears. The integration of the time-history on the "state space" promises the best avenue for quantitative evaluation of the operator's performance.

Reduction of the state space to a condensed matrix form allows it to be stored as an operator performance record. Analysis of a group of such records, correlated with other criterion measures, should reveal patterns of "good" and "poor" control performance, and allow future evaluations of operator performance by comparing those patterns with "good" control performance.

8. SWITCH MANIPULATION LINKAGE

To support time-motion studies of control room layouts and procedures, software was developed to determine the time/location sequence of the operator's manual interaction with the simulator. This program examines a data tape produced by the PMS data collection system and analyzes the operator control manipulation sequence by examining changes in the DI (Digital Input) section of the data. This corresponds to switch manipulations that serve as operator input to the simulator. The sequences or pattern of these manipulations can support time-motion studies of the control room layout for various procedures or scenarios. Several outputs are available:

1. Switch Manipulation Linkage output consists of a time-history of all manipulations. Time, to a one-second accuracy is available as well as switch location on the panels.

2. Digital Input Switch Manipulation Matrix is really a summary of manipulation history. It allows an overview of which controls were activated and with what frequency. This form of analysis can also be used to develop sequence or pattern checks to monitor operator compliance with procedures. The matrix for a perfectly correct procedure becomes a template suitable for detecting any spurious manipulations which may be operator errors. Flagging those to the operator could help him detect manipulations he really did not intend to make.

3. Link Matrix of the switch manipulations examines where a switch action is located relative to the previous action. This gives a pattern

of operator travel in the control room, and can identify poorly located controls which are increasing the operator's work load.

9. INFORMATION RATE ANALYSIS

In order to address the problem of operator information processing, software was developed to process performance measurement system data tapes and extract from them information on the rate at which information is being presented to the operator in various scenarios.

This was used to evaluate a Loss of Coolant Accident, design basis accident for this PWR design. The accident is accompanied by 8 bits of information to the operator (lights). The next second gives the operator 113 bits of information to digest; successive seconds yield 283 (a peak), 97 and 25 bits of information. Five seconds into the accident the operator has been presented with 576 flashing lights or 'bits' of information which are supposed to reveal to him the state of the plant. His job is to integrate and interpret this information and take appropriate action. During the following thirty seconds, the operator contrives to be bombarded with information at an average of 28 bits per second. The normal operations bit rate was about 1 bit per minute. In the following minutes the bit rate rapidly decreases to approximately the levels observed during the reactor startup, 1 bit per second. This examination gives the correct impression; there are an awful lot of lights to keep track of.

What does this all mean? Taken alone the comparison of this reactor startup and LOCA data serves to illustrate and document the extremely high data rate to which the operator is subject in a major casualty. This presentation at rates 20 to 100 times a normal rate could clearly saturate the operator's information processing abilities. This would tend to support findings in surveys that in major casualties the operator tends to "tune out" the mass of information being presented and specifically seek out cardinal bits on which to base decisions. If that is the case is anything gained by this mass presentation? Or does it result in a dysfunction by saturating the operator's visual information channel and increasing stress levels early in the casualty?

Any substantial conclusion would require closer examination of more data runs with specific questions in mind. The advantages and disadvantages of various information schemes will continue to be hotly discussed. But this technique for computer evaluation of the information rate and information patterns offers a unique tool for investigating many of the questions which have already been raised in this area.

10. STANDARDS DEVELOPMENT

To support development of ANSI Standard N-660, a detailed evaluation of operator performance during a large Loss of Coolant Accident (LOCA) was conducted. Operator time response to a one-second accuracy was studied for a series of LOCA exercises. Statistical evaluation of that data yields an objective basis for assignment of control actions to an operator by his time response capabilities. Determinations of error rates are also possible.

11. SUMMARY

The development of a Performance Measurement System for training simulators makes possible major improvements in the conduct of training and research. Using the simulator computer as a data taker gives a completeness and accuracy beyond the capabilities of either the trainer or researcher. The evaluation of operator performance based on this objective data can be used to support training decisions, standards development, or basic human factors research. There are limitations, and the required simulator time and software development is expensive. But it represents a powerful tool now available to help answer the many questions concerning operator performance in and training for the power plant control room environment.

REFERENCES

Electric Power Research Institute, "Performance Measurement System for Training Simulators," NP-783, Research Project 769-1 (May 1978).