ornl

OAK
RIDGE
NATIONAL
LABORATORY

UNION
CARBIDE

NUREG/CR-2586
ORNL/TM-8236

NUREG/CR--2586

DE82 009406

A Survey of Methods for Improving Operator Acceptance of Computerized Aids

P. R. Frey
R. A. Kisner

MASTER

Prepared for the
U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Under Interagency Agreement DOE 40-550-75

OPERATED BY
UNION CARBIDE CORPORATION
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-2586
ORNL/TM-8236
Dist. Category RX

Contract No. W-7405-eng-26

INSTRUMENTATION AND CONTROLS DIVISION

A SURVEY OF METHODS FOR IMPROVING OPERATOR ACCEPTANCE OF COMPUTERIZED AIDS

P. R. Frey R. A. Kisner

Manuscript Completed - February 1982
Date Published - April 1982

Prepared for the
U. S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555
Under Interagency Agreement DOE 40-550-75

NRC FIN No. B0438

Prepared by the
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
for the
U.S. DEPARTMENT OF ENERGY

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

CONTENTS

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

A SURVEY OF METHODS FOR IMPROVING OPERATOR ACCEPTANCE OF COMPUTERIZED AIDS

P. R. Frey and R. A. Kisner

Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

HIGHLIGHTS

The success of current attempts to improve the operational performance and safety of nuclear power plants by installing computerized operational aids in the control rooms is dependent, in part, on the operator's attitude toward the aid. Utility experience with process computer systems indicates that problems may already exist with operator acceptance of computerized aids. The growth of the role that computers have in nuclear power plants makes user acceptance of computer technology an important issue for the nuclear industry. The purpose of this report is to draw from the literature factors related to user acceptance of computerized equipment that may also be applicable to the acceptance of computerized aids used in the nuclear power plant control room.

A review of the available literature revealed about seventy papers that deal with acceptance problems in computerized systems. Two attempts to define and measure the characteristics of a user-acceptable system in nonnuclear industries form a basis for future work on this subject in the nuclear industry. Operator acceptance of computerized aids can be influenced during design, operator training and system operation. Design methods for improving acceptance include allowing the user to participate in the design process, considering acceptance principles in the allocation of functions between the man and machine, minimizing the length and variation of the system response times, tailoring the dialogue to the task and user, integrating the system into the control room and providing usable system documentation. During operator training, acceptance considerations include providing adequate detail on the purposes and limitations of the system, ensuring that the training situations approximate the expected operational situations and providing training for subsequent generations of operators. The primary acceptance considerations during operation are system availability and system calibration.

Although these general principles and guidelines can be used to improve operator acceptance of computerized aids, additional research is required to more accurately define the characteristics of a user-acceptable system for nuclear power plant operators. The survey methods and data reviewed in this report provide a basis for that research.

INTRODUCTION

The success of current attempts to improve the operational performance and safety of nuclear power plants by installing computerized operational aids in the control rooms is dependent, in part, on the operator's attitude toward the aids. Methods for producing positive user attitudes toward innovations have been well researched by the military and the data processing industry. The purpose of this report is to draw from the literature factors related to user acceptance of computerized equipment that may also be applicable to the acceptance of computerized aids used in the nuclear power plant control room.

Utility experience with process computer systems indicates that operator acceptance problems may already exist. A survey made in 1977 for the Electric Power Research Institute (EPRI) showed that only 17% of the process computer systems in fossil and nuclear power plants had a good performance rating; 50%, a fair rating; and 33%, a poor rating.[1] One of the problems most often cited in the survey was inadequacies in the man-machine interface.

The application of human factors engineering to computer systems began as early as 1960 and has expanded to the point that a recently compiled bibliography of the literature on human factors in computer systems required a review of more than 4000 documents.[2,3] Although a large volume of research has been performed in this area, many computer systems that fail to meet their performance requirements do so because the design of the man-computer interface is inadequate.

Both regulatory requirements and industry advancements have broadened the role of computers in nuclear power plant operations. Although the U.S. Nuclear Regulatory Commission (NRC) functional criteria for the Emergency Response Facilities* do not require the use of computer technology, many of the functions can be implemented economically and reliably using computer systems. The industry has also developed new roles for computers in advanced control rooms and operational aids such as disturbance analysis systems and alarm filtering systems.

The growth of the role of computers in nuclear power plant control rooms makes user acceptance of computer technology an important issue. Because user acceptance of the system affects man-machine performance, it is a valid criterion for selection among otherwise equal alternatives in which the basic performance and design objectives have been met.

A review of the available literature revealed about 70 papers that deal with acceptance problems related to computerized systems. These papers describe a diversity of applications, such as management information and decision aids, medical diagnosis aids, aviation and aerospace systems, military decision aids, data processing systems, as well as

---

*The Technical Support Center, the Operational Support Center, the Emergency Operations Facility, the Safety Parameter Display System, and the Nuclear Data Link.

chemical and mechanical process control systems. Much of the work that has been done in user acceptance has not been generic in nature but rather has been applied to specific items of equipment.[4-6] While the types of personnel and environment involved in these studies (e.g., military and aviation applications) prevent direct application of the results to the nuclear industry, general principles may be derived from this work.

This report presents the results of these studies and discusses them in the context of the nuclear power plant control room. The first section of the report discusses the implications of user acceptance of aids. The second section reviews results of attempts to develop criteria for user-acceptable systems. The final section summarizes some of the practical methods to enhance the operator's acceptance of computerized aids.

IMPLICATIONS OF ACCEPTANCE

The results of the rejection of a computerized aid may be a loss of investment in the development of the aid, loss of potential capability provided by the aid, or reduction of performance of the man-machine system. Suppliers, owners, and regulators of operational aids all have interests that will be affected by rejection of the aid (i.e., sales, profits, and public safety).

Also of interest, but not the major concern in this work, is the excessive acceptance of a computerized aid. "Overreliance" is a better term than "acceptance" in this context. The use of humans as monitors of automatic systems is almost universally practiced (the exceptions being systems with a low consequence of failure and systems in remote or hazardous locations). If a human is to monitor a system's performance effectively, he must have an internal model of the system for comparison (i.e., an understanding of the system's functions and expected responses). Such a model is constructed, at least in part, from interaction with the system. Overreliance on a system is characterized by an improper or overly optimistic internal model of the system, resulting in misapplication of the system or failure to adequately monitor or verify the system. In a series of experiments on the use of partially accurate data obtained from a computer aid, users were unable to reliably detect random errors in the system's output.[7] Although the effects of extended experience with the aid were not evaluated, the conclusions indicate that uncritical acceptance or overreliance should be a concern, especially for high-reliability systems with "soft" (undetected) failure modes.

Research on methods for maintaining a user's critical assessment of a computerized aid is lacking. While overreliance is not the subject of this report, it will need study as systems become more reliable and accepted, particularly as the consequences of soft failures increase.

MEASURES OF ACCEPTANCE

Because operator acceptance of computerized aids necessarily involves human attitudes and behavior, it is difficult to define or measure. Man-machine system performance is easier to define and measure (e.g., the time required to accomplish a task or the number of errors committed in performing a task), but performance is not always indicative of acceptance, although the two are related. For example, a study of the effects of "lockout" on computer-aided problem solving indicated that when a problem solver was not allowed access to the computer for 5 min after the presentation of the results, the performance was improved (better solutions, less computer time, less total working time).[8] The delay induced the user to concentrate more on the problem to be solved and less on the tactics being developed to solve it. However, even though it improved performance, this lockout decreased user satisfaction and acceptance.

Utilization of the aid is another indicator of acceptance. However, if the user cannot accomplish the task without using the aid (e.g., data entry into a data base management system) or if the alternative to using the aid creates an unacceptable burden on the user, the user is forced to use the aid in spite of its "unacceptability." Therefore, utilization is a good indicator of acceptance only if the task can be performed using other resources.

Another way to measure acceptance is by survey of the users of the aid. Although this is commonly used for post-mortem purposes (i.e., to determine the reasons for nonacceptance), it might be used prior to the development of an aid to determine the characteristics of an aid that the user perceives as acceptable. A survey of the users of a decision aid proposed for the U.S. Navy is an example.[9] The design criteria, listed in order of priority as indicated by the responses of 200 officers and enlisted personnel, are as follows:

1. Ease with which the information output can be assimilated and interpreted;

2. Speed of operation, ease with which desired items of information output can be called up;

3. Ease with which the input data needed for using the information aid can be obtained and entered;

4. Reliability, freedom from maintenance problems, short mean time to repair;

5. Compatibility with existing systems, absence of interference with other system functions, stand alone, ease of installation;

6. Minimum of interference with execution of assigned responsibilities, override capability;

7. Limited operational training required, needed training locally available;

8. Freedom from extensive software support, needed support readily available;

9. Limited maintenance training required, needed training locally available.

Although such a list indicates an ordering of some of the broad requirements in a system's development, a more detailed breakdown is necessary for a quantitative or comparative analysis.

Another example is a survey of data processing professionals in Germany that was conducted to determine a measure of the user-perceived quality of a computer system.[10] First, 300 experienced users of interactive systems were asked to state system properties which influenced their perception of the quality of a system. Subsequently, 233 users graded the importance of 100 system requirements to user-perceived quality. Finally, the authors of that study extracted seven independent factors that the users rated as desirable. These factors and some of the applicable system requirements (listed in order of desirability) are as follows:

1. Self-descriptive

- explain system requests to the user if and when necessary,
- supply explanations in different detail and different format upon user request,
- supply help features pertinent to any dialogue situation,
- explain each command and subcommand upon user request,
- give a clearly arranged presentation of system functions,
- give decision aids if tasks cannot be executed as desired,
- provide user guidance for the dialogue by prompting,
- supply information about the current system status if desired.

2. Under user control

- allow interruptions of a task to start or resume another task,
- allow canceling of processes without detrimental side effects,
- allow canceling of dialogue steps,

- be permanently available,
- immediately detect syntax errors.

3. Easy to learn

- facilitate the learning of system use without requiring the user to consult manuals,
- be usable without special data processing knowledge,
- make few assumptions about user's prior knowledge of system structures and functions,
- support user input by menu techniques.

4. Transparent

- obviate, as far as possible, the need for the user to perform clerical or housekeeping activities,
- manage formatting, addressing, and memory organization without bothering the user,
- make system-level decisions without consulting the user,
- accept free-formatted command input,
- have a command language easy to understand, apply, and remember,
- have a command language that is homogeneous in syntax,
- make repetitive or routine input unnecessary.

5. Corresponds with user expectations

- behave similarly in similar situations,
- let the user recognize effects of his input,
- be tolerant toward erroneous user input,
- provide the same response times to equal activities.

6. Adaptable to user experience level

- allow user to extend the command language,
- provide system messages with different levels of detail dependent on user experience level,
- provide shorter ways for the trained user to perform his tasks,

- permit user to define a user experience level,
- permit clustering of commands with a new name.

7. <u>Fault tolerant</u>

- insist only on partial retyping if previous input was erroneous,
- tolerate typical typing errors,
- give error messages with correction hints,
- enable user to submit concatenated commands as input,
- give error messages in full text.

These characteristics can be used as a starting point for a quantitative definition for comparative analysis of the user-perceived quality of a computer system. Weighting factors for each of these requirements and a methodology for measuring the extent to which a proposed system meets the requirements are yet to be developed.

Although this study is a starting point for the development of a procedure for predicting acceptance of computer-based aids in nuclear power plant control rooms, at least two concerns should be addressed. (1) Since this survey was conducted on a sample of data processing professionals, a similar survey should be conducted on nuclear power plant operators. The results would show some changes in the priorities and some additions to or deletions from the list. (2) Because the list is task-independent, the hardware portion of the man-machine interface is not covered. Traditional human factors sources can be used to evaluate certain aspects of the hardware portion of the man-machine interface (anthropometry, visual acuity, etc.). However, little quantitative work has been performed to study user acceptance of displays and input-output (I/O) devices, and the work that has been performed is task or system-specific. Because of the strong relationship between the task and the hardware interface, it may not be possible to develop meaningful measures of acceptance of the hardware interface. However, general guidelines do exist; some of these will be discussed later in this report.

FACTORS THAT INFLUENCE ACCEPTANCE

User acceptance of computerized aids can be influenced by decisions made during all stages of system development and implementation. This section describes some factors that affect user acceptance, covering the major points reported in the literature. For the many system characteristics and design decisions not mentioned here, traditional human factors engineering offers the best first approximation to a user-acceptable design. This is true, in particular, for task-dependent characteristics, such as the choice of I/O devices and display formats.[11,12]

The influencing factors are divided into three categories: design, training, and operation.

Design

User participation

User participation in the design process is a valid method for enhancing operator acceptance of new technologies.[4,9,13,14] When the user participates in the various stages of system development from concept through detailed design, he brings a unique perspective based on his job characteristics (e.g., information load, situation complexity, preferred practice, time demands, and operational constraints). However, user-preference information by itself is not necessarily the best basis for improving overall system performance and should be supplemented by other, more objective data. User (or user community) participation in the design process helps the designer and the user focus their attention on the real operational problems and helps the user understand the rationale for the final design, in which the designer may have necessarily compromised user preferences.

Allocation of functions

The allocation of functions is the process of assigning system functions to the man and the machine. These assignment decisions determine the characteristics of the user's role, and they affect personnel selection and training. As currently practiced, these decisions are made unconsciously more often than consciously.

Since a man-machine system is designed to accomplish some overall goal, there are many constraints that guide the allocation process. The goal itself may dictate allocation of a specific function to a machine because its speed, accuracy, precision or other capabilities exceed those of the man. On the other hand, the goal may dictate allocation of other functions to the man because his cognitive abilities, flexibility, or other capabilities exceed those of the machine. Other constraints such as reliability and cost also influence the allocation of functions.

The functions that remain after the initial allocation process are the basis for the subsequent determination of an acceptable role for the user. Many lists of the relative capabilities of men and machines have been compiled for this purpose,[15] and from these lists, guidelines have been derived to serve as a basis for the allocation of functions. For example, (1) it is generally acceptable to have a machine perform continuous servo tasks and frequent, repetitive tasks, but not high-level supervision, overall system monitoring, and decision making; (2) the user's role should allow the use of skills that are important to him and should provide flexibility in the manner of accomplishing his tasks; (3) the user's responsibilities should be in accordance with his authority.[5] However, these guidelines are difficult to apply.

Additional work is needed to define criteria that are more useful than these guidelines. In a related study on the allocation of functions, Price, Maisano and Van Cott included the evaluation of operator acceptance as one step in the allocation process.[16] Follow-on work, which consists of developing and applying criteria for their allocation process, should provide acceptance guidelines that can be applied to computerized aids.

System response time

Concentration, which is essential to problem solving, requires continuity of thought. A computerized aid should allow a user this continuity of thought by responding to commands within an acceptable period of time. This characteristic allows the user to concentrate on the problem at hand rather than being preoccupied with the mechanics of using the aid.

There are two design goals with respect to system response time: (1) minimize its magnitude and (2) minimize its variability.

Response time magnitude. System response time is defined as the time lapse between the termination of a request by the user and the completion of the system's response to that request. All systems have a set of response times that range from very short (e.g., the system echo of a keystroke) to very long (e.g., the execution of complex algorithms or simulations). The duration of a system's response time has a strong effect on user acceptance.

Acceptance seems to possess a threshold-like relationship with system response time. For example, a system whose response time for keystroke echo is 10 s would not be more acceptable than one whose response time is 1 min. Both are too long because the threshold for this activity is about 0.1 s. These thresholds in response times occur because of the demands placed on the user's short-term memory by delayed response and the user's desire to quickly attain "closure."[17]

Engel and Granda list two tables of suggested response times for interactive systems (Tables 1 and 2).[11] A simpler breakdown of response times is shown in Table 3.[18] The acceptance of a system may also be nonmonotonic with respect to system response time. That is, there is an optimum response time range for a given function, and faster or slower response times may result in degraded acceptance;[19] however, research in the area of excessive response speed is too sparse to draw any conclusions.

Table 1. System response times as a function of system recognized activity[11]

System Interpretation	Response Time Definition	Maximum Acceptable Response Time (s)
Key Response	Key depression until positive response; for example, "click"	0.1
Key Print	Key depression until appearance of character	0.2
Page Turn	End of request until first few lines are visible	1.0
Page Scan	End of request until text begins to scroll	0.5
XY Entry	From selection of field until visual verification	0.2
Function Selection	From selection of command until response	2.0
Pointing	From input of point to display of point	0.2
Local Update	Change to image using local data base; for example, new menu list from display buffer	0.5
Host Update	Change where data is at host in readily accessible form; for example, a scale change of existing image	2.0
File Update	Image update requires an access to a host file	10.0
Simple Inquiry	From command until display of a commonly used message	2.0
Complex Inquiry	Response message requires seldom used calculations in graphic form	5.0-10.0
Error Feedback	From entry of input until error message appears	2.0

Table 2. System response times as a function of user activity[11,17]

User Activity	Maximum Response Time (s)
Control Activation (for example, keyboard entry)	0.1
System Activation (system initialization)	3
Request For Given Service:	
Simple	2
Complex	5
Leading and Restart	15-60
Error Feedback (following completion of input)	2-4
Response to ID	2
Information on Next Procedure	<5
Response to Simple Inquiry from List	2
Response to Simple Status Inquiry	2
Response to Complex Inquiry in Table Form	2-4
Request For Next Page	0.5-1
Response to "Execute Problem"	<15
Light-Pen Entries	1
Response to Complex Inquiry in Graphic Form	2-10
Response to Graphic Manipulation	2
Response to User Intervention in Automatic Process	4

Table 3. Suggested system response times[18]

Lexical	Reflexive actions	50 ms
Syntactic	Semi-conscious actions	500 ms - 4 s
Semantic	Conscious actions	tens of seconds

Response time variability. Another aspect of system response time that affects acceptance is the variability of system response times for a given function. In an experiment involving a message retrieval task, a system with a highly variable response time caused a significant decrease in both user performance and user acceptance.[20] Although it appears that no quantitative work has been done to study system response variability, some associated data are available from studies in experimental psychology.[21] In these studies, subjects were asked to estimate whether the time interval between successive auditory stimuli was the same as, shorter, or longer than a reference time interval. The results are summarized in Table 4. As expected, the variation of the estimates increased as the time interval became longer. Unlike the operators of a complex process, these subjects devoted their full attention to the task of detecting the intervals; therefore, one would expect that larger variations would not be detected by a user processing information from more than one source. So the data in Table 4 provide a lower limit of the detectable variation of reponse time intervals. Additional work is required to determine an upper limit of the detectable variation of response time (probably as a function of mental work load caused by auxiliary tasks).

Dialogue

Dialogue, defined as two-way man-computer conversation, has a great deal to do with user acceptance of the system. The term applies to man-computer systems in the sense that the user and the programmer, via the computer, communicate with each other for the purpose of solving a problem or performing an action. Some of the more important characteristics of man-computer dialogue are initiative, flexibility, complexity, power, and information load. Each of these will be discussed from the viewpoint of user acceptance.

Dialogue initiative. Dialogue initiative is concerned with whether the user or the computer initiates the individual information transactions within the dialogue. If the computer asks questions, presents alternatives, etc., and the user responds, the dialogue is said to be computer-initiated. If the user inputs commands without such computer prompting, the dialogue is said to be user-initiated. Variable initiative dialogues allow the user (or occasionally the system) to select either user- or computer-initiated dialogue.

Table 4. Perceptible variation in time invervals[21]

Time Interval(s)	Undetected Variation
0.6-0.8	±5%
2-4	±8%
6-30	±10% to ±15%

The selection of an acceptable dialogue mode should be based on the type of task and the experience level of the user.[12] For task initiation and associated high level commands, the user-initiated dialogue is favorable, but for highly structured situations, such as well-defined sequences of steps, the computer should relieve the user of the necessity of remembering the sequence by using computer-initiated dialogue. Additionally, inexperienced users prefer and perform better with computer initiated dialogue[22] because a large knowledge base is required with user-initiated dialogue to determine which of the available commands will accomplish the intended action. The selection of user-initiated dialogue for inexperienced users has been a major factor in the rejection of many systems.[12] However, as users gain experience, their preference shifts to user-initiated dialogue. This shift makes the variable-initiative dialogue attractive because it allows the user to select the appropriate mode of dialogue based on preferences, needs, and circumstances. A more commonly used alternative to variable initiative dialogue is thorough familiarity with the system, along with frequent, routine use of the system.

Dialogue flexibility. Dialogue flexibility enables a user to accomplish a given function in a number of ways. High flexibility can be achieved by providing a large number of commands or by allowing the user to define or redefine commands.[12] A high degree of flexibility is desirable for experienced users. Inexperienced users tend to adopt a less flexible subset of the available command language for use. Although this does not seem to affect user acceptance (provided an adequately powerful command subset can be adopted), it does tend to waste resources and, in some cases, increases the user's error rate.[23]

Dialogue complexity. Dialogue complexity refers to the number of options available to the user at a given point in the dialogue. Low complexity can be achieved by using few commands or by partitioning the commands so that the user selects from a small number of options at any given time.[12] No results that relate command language complexity directly to user acceptance were found. Results of experiments indicate that medium complexity (12 options) yields more interaction and variety of command usage than high complexity (21 options) or low complexity

(3) options), but performance results were not consistent.[24] In another study on the relative balance of commands (functions) and arguments (variables), a command language with few commands and many arguments was more useful than one with many commands and few arguments.[25] The capacity of short-term memory may not be the limiting factor in command language complexity, and the "magical number seven plus or minus two"[26] should not be applied uncritically.[12]

Dialogue power. Dialogue power is the amount of work accomplished by the system in response to a single user command. A high degree of power in an interactive language is usually accompanied by either high complexity or restricted generality.[12] For example, a highly complex dynamic simulation might require that a large number of initial conditions and independent parameters be entered as arguments, resulting in a general-purpose simulator. Another implementation may relieve the user of the task of entering the initial conditions by assuming some default conditions, resulting in a less generalized simulator for use only under certain conditions. Either implementation in the wrong context will decrease user acceptance.[27]

Dialogue information load. Dialogue information load is a measure of the degree to which the interaction absorbs the memory and/or processing resources of the user.[12] Specifying a desirable information load is difficult because the use of cognitive processing resources becomes more efficient as the user gains experience. Both excessive and inadequate information loads can adversely affect user performance and acceptance. Several suggestions for reducing information load follow:[12]

1. Use display devices with higher channel capacity (e.g., graphics).

2. Perform dynamic reformatting of displays to match immediate user requirements.

3. Provide commands of appropriate power for immediate user requirements.

4. Use appropriate command complexity.[28]

5. Move clerical operations within the system.

6. Use default values.

7. Preprocess information to relieve the user of information intergration tasks.

Guidelines. Many guidelines exist for the design of man-computer dialogues.[11, 12, 29-31] Although most of these do not specifically address user acceptance, a designer who uses these guidelines will profit by avoiding many previously experienced pitfalls. These represent a large body of knowledge which is not practical to condense here.

As an example of some specific guidelines, this survey of the users of a NASA tracking system illustrates several concerns in the user acceptance of man-computer dialogue:[22]

1. Commands should be standardized; similar functions in different systems should have the same names and formats.

2. Commands should be approximately three characters in length.

3. The number of arguments in a command should be kept to four or less.

4. The delimiter between command arguments should be one that is easy to type rather than one that is more descriptive but harder to type. For example, a space is preferred for the delimiter rather than a comma (,), slash (/), or equal (=), which require more typing effort.

5. Frequently used commands should be simple; less frequently used commands should be more descriptive.

6. Error and status messages should be descriptive and explanatory at the expense of being long.

7. Frequent messages should be abbreviated and short at the expense of descriptiveness.

8. Error messages that have no possible operator response should not be displayed to the operator; they should be logged separately if they are important for maintenance activities.

9. Coded error messages should be avoided.

10. Audio alarms should be used sparingly and only for critical and unexpected conditions.

11. Display blinking should be used for only the most critical faults.

12. All attention-getting devices should be capable of being turned off after they have obtained the operator's attention.

13. A single-page, quick-reference document on command format and usage should be available to the operator.

14. The operator's work station should be designed so that access to the documentation is rapid and convenient; this primarily means counter space and storage space within the operator's reach.

15. Frequently used programs, such as operations programs, should be designed to be easy to use.

16. Infrequently used programs, such as support or utility programs, should be designed to be easy to learn.

The users in this survey were interested in a dialogue that is adapted to the operating environment. However, the guidelines proposed by these users will vary from one user population to another. System designers should use these guidelines as a starting point for the development of a dialogue acceptable for their specific user population.

System integration

Integration of the aid into the control room contributes to the acceptance of the system. Much can be done in the design of the aid and operator training to help achieve integration. Some examples are (1) the design of the displays for viewing by operators from various positions in the control room, (2) the use of colors, symbols and abbreviations in the design of the displays that is consistent with other usage in the control room, and (3) revisions to operating and maintenance training, procedures, and practices to ensure that the personnel know how and when the aid should be used.[6]

Some control room modification may be necessary to achieve succcessful integration. The extent of the modification will depend on the functions of the aid, the activities of the primary user, and the layout of other controls and instruments. Because of the diversity of control room layouts, a customizing approach should be used in the design of an aid to ensure adequate integration in the control room. For example, the position of the aid's I/O devices in the control room should be considered in (1) the choice of I/O devices (resolution, font, viewing angle, size); (2) the choice of data presentation formats; and (3) the choice of dialogue type (computer-initiated, user-initiated).

Documentation

Adequate documentation, both for the user and the maintainer, is necessary for successful system operation and acceptance. The EPRI study[1] indicates that system documentation had been both untimely and inadequate. Full, correct, up-to-date documentation should be available to both users and maintainers prior to system startup and during operation. Some of the characteristics of documentation that users indicate as desirable but frequently lacking are[4,6]

1. Explanation of the "how and why" of system functions,

2. Organization for "real-world" usage (implies an understanding of how the documentation will be used),

3. Suitability for both normal and error conditions (provide the user with a quick reference for corrective procedures).

Training

Training is one of the most important factors in user acceptance of systems,[4,6] but it frequently does not receive the attention it deserves because of contractual difficulties with the system supplier, schedule delays, and other compromises. For example, the EPRI survey indicates that most plant engineers and chief operators thought that training was inadequate.[1]

As indicated earlier, the user should participate early in the system design process. Experience has shown that acceptance suffers as a result of a management policy of involving users for the first time during training.[13]

Content

Training should take into account the background and experience of the users. For example, older users or users unfamiliar with the new technology generally take longer to adjust to innovations and need different types of introductory information.[32] A rapid training pace or the omission of background material will hinder initial acceptance, degrade performance, and may also lead to long-term rejection.

In addition to the usual manipulative and interpretive details, training should also include the purposes, limitations, design assumptions, and restrictions of system operation. For example, the rejection of a new naval target-classification aid was attributed to users who were not trained to understand its purpose and operation. Consequently, they failed to fully accept the aid and developed biases against it. These biases led to improper maintenance practices, which further reduced operating effectiveness and strengthened their biases.[6] Study of the aid's purpose and limitations is necessary for the operator to understand how the aid affects his role in the operation of the plant. This is important to ensure acceptance of decision aids, such as the Disturbance Analysis and Surveillance System (DASS), which may be installed in existing control rooms for use by experienced plant operators.

Military experience has suggested that to gain acceptance of decision aids, users must be taught to understand the aid's internal processes. Hanes and Gebhard concluded that users of a decision aid want to know with a high degree of certainty what the system hardware and software are doing and to have a high degree of control over the procedure adopted by the aid before they will comfortably accept the computer's recommendations.[33] In Mackie's study,[9] many users of a decision aid expressed their need to fully understand how that system's software is designed and functions so that they could decide for themselves the meaning and limitations of the output information. Experienced users expressed concern that naive users might uncritically accept the system's output, and they concluded that users should know what factors were and were not considered by the designer. In discussing a simpler experiment, Shaffer[34] stated that a user can sucessfully monitor a decision-making computer only if he understands the logic used by the computer. Several other sources state similar conclusions[28,35,36]. All of these examples make more credible the argument that the internal processes of aids that supplement the user's cognitive processes must be understood by the user to ensure acceptance and effective system monitoring. This is an area that is in need of additional research, with particular application to the process control operator.

Environment

Because training is usually (regrettably) the user's first exposure to the equipment, the training should be carefully planned so that the user's first impressions will be favorable. Although it is not necessary to delay training until the entire system is working, the portion of the system to be used in training should be thoroughly pretested.

The system output received by the user during training should resemble the output the user will receive in the field. One reason for the rejection of the naval target-classification aid was that the quality of system data in the field was poor, compared with the data from the system during training.[6]

Subsequent generations

Most systems will have a lifetime sufficiently long enough to require training of new users long after the system has been installed. Because of the limited nature of these systems, it is unlikely that a training staff and equipment will be available from the original system supplier after the initial users are trained. To ensure system acceptance by these new users, adequate training will be required. The data processing industry is experimenting with self-tutorial systems that provide instruction on the use of the system along with examples and exercises.[12] This embedded training can be used to ensure adequate training for a system with a long life cycle.

Operation

The operational phase has more potential for maintaining or degrading the acceptance level than any other phase of system development. A system must be reliable to be accepted. At least two aspects of reliability are known to affect acceptance: availability of the system[37] and quality of system output.[4,6] These aspects are the responsibility of both the designer and the maintainer. Availability depends on mean time to failure and mean time to repair; system quality depends on periodic maintenance and calibration. No quantitative results on acceptable tolerances for these reliability measures were found in the literature.

Another operational factor that affects acceptance is situation complexity. This is related to the need for training on the system's internal processes. As an operational situation becomes more complex, the user's confidence that the designer has adequately anticipated the situation will decrease, particularly if the events have not been previously encountered. Users often choose to ignore the system if their perception of a situation disagrees with the system's assessment.[33,38,39] This reaction by the user can be either a benefit or a hazard, depending on the appropriateness of the system's output. The correct degree of acceptance depends on the quality of the system's output, and to maintain that degree of acceptance requires that the user be equipped with the resources (training and auxiliary equipment) to monitor the system.

SUMMARY AND CONCLUSIONS

Operator acceptance of computerized aids is important to utilities, regulatory agencies, and system suppliers. Either inadequate acceptance of or unquestioned reliance on computerized aids can affect both plant availability and plant safety.

Methods to increase user acceptance must be implemented during design, training, and operation. These methods involve helping the operator conform to the equipment where necessary as well as ensuring that the equipment conforms to the operator where possible. The process of conforming the operator to the equipment is training. The process of conforming the equipment to the user involves design, operational, and maintenance decisions throughout the life cycle of system development and use. These decisions are necessarily influenced and restricted by cost and available technology.

Some of the methods to enhance user acceptance of computerized aids have been presented in this report for the purpose of merging these ideas for use in the nuclear industry. Although most of the human factors guidelines for computer systems compiled in the literature have been omitted in this report, the portions of these guidelines where user acceptance is a key issue have been included.

A necessary next step in this work is to more closely examine the acceptance problems in the nuclear power plant control room. Although most of the data presented in this report come from nonnuclear industries, the general principles are applicable to operational aids installed in the nuclear power plant. But, to provide more specific guidelines, the characteristics of user-acceptable aids must be investigated for the user population, that is, nuclear power operators. The survey techniques and, to a certain extent, the system characteristics desired in the military and data processing studies[9,10,22] discussed in this report are a foundation for this investigation.

Methods for maintaining the user's critical assessment of information from decision aids also need additional research. The problem of overreliance is the opposite of inadequate acceptance, but it has similar consequences. Methods for detecting soft failures in systems should be developed, with particular emphasis on verification under emergency conditions.

The evolution of man-machine systems is rapidly approaching the point where the question is not *can it be done*, but *how should it be done*? Advances in hardware and software technology are providing more flexibility in the design of the role of the user than was previously attainable. The importance of effective human performance should continue to motivate the design of user-acceptable systems.

REFERENCES

1. Macro Corporation, Documentation of Utility Experience With Process Computers in Power Plants: Final Report, EPRI NP-290 (May 1977).

2. J.C.R. Licklider, "Man-Computer Symbiosis," IRE Trans. Human Factors Eng., HFE-1, 4-11, (March 1960).

3. H. R. Ramsey, M. E. Atwood, and P. J. Kirshbaum, A Critically Annotated Bibliography of the Literature of Human Factors in Computer Systems, SAI-78-070-DEN (May 1978).

4. M. Mecherikoff and R. R. Mackie, Attitudinal Factors in the Acceptance of Innovations in the Navy, Human Factors Research, Inc., Tech. Rep. 784-1 (June 1970).

5. H. E. Price, E. E. Smith, and R. A. Behan, Utilization of Acceptance Data in a Descriptive Model for Determining Man's Role in a System, NASA CR-95 (September 1964).

6. H. K. Simpson and E. L. Parker, Maintenance Status and Fleet Acceptance of ASPECT Target Classification Equipment, Human Factors Research, Inc., Tech. Rep. 206-33 (November 1965).

7. S. M. Halpin, "Utilization of Partially Accurate Output From a Computer Aid," U. S. Army Research Institute for the Behavioral and Social Sciences (October 1976).

8. B. W. Boehm, M. J. Steven, and R. A. Watson, "Interactive Problem-Solving: An Experimental Study of "Lockout Effects," AFIPS Conf. Proc. (1971).

9. R. R. Mackie, "Design Criteria for Decision Aids - The Users Perspective," Proc. Human Factors Soc., 1980, pp. 80-84.

10. W. Dzida, S. Herda, and W. D. Itzfeldt, "User Perceived Quality of Interactive Systems," IEEE Trans. Software Eng. SE-4(4), 270-296 (July 1978).

11. S. E. Engel and R. E. Granda, Guidelines for Man/Display Interfaces, IBM Poughkeepsie Laboratory, Tech. Rep. TR-00.2720 (December 19, 1975).

12. H. R. Ramsey and M. E. Atwood, Human Factors in Computer Systems: A Review of the Literature, SAI-79-111-DEN (September 1979).

13. J. O. Hol, G. Ohra, E. Edsberg, and F. Petterson, Retrofitting of Control Rooms with Computer-Based Systems, OECD Halden Reactor Project, Rep. HWR-25, (May 1981).

14. J. E. Rijnsdorp, "A General Review of the Field of Man/Machine Interfaces in Terms of Psychological-Social Effects Involved; Treating Needs, The Results of Recent Projects and Future Projections for the Field," Proc. 6th Annu. Advanced Control Conf., Purdue Univ. (1980).

15. E. J. McCormick, Human Factors in Engineering And Design, 4th ed., McGraw-Hill, New York, 1976.

16. H. E. Price, R. E. Maisano, H. P. Van Cott, The Allocation of Functions in Man-Machine Systems: A Perspective and Literature Review, BioTechnology, Inc. (November 1981).

17. R. B. Miller, "Response Time in Man-Computer Conversational Transactions," AFIPS Conf. Proc. 33, 267-277 (1968).

18. J. D. Foley and V. L. Wallace, "The Art of Natural Graphic Man-Machine Conversation," Proc. IEEE 62(4), 462-471 (April 1974).

19. W. M. Newman, "Interactive Graphical Response and its Effects on Display Systems Performance," Proc. Int. Symp. Man-Machine Systems 4 (September 1969).

20. L. H. Miller, An Investigation of the Effects of Output Variability and Output Bandwidth on User Performance in an Interactive Computer System, Information Sciences Institute, Rep. ISI/RR-76-50 (December 1976).

21. S. S. Stevens, Handbook of Experimental Psychology, Wiley, New York, 1951.

22. R. L. Chafin and T. H. Martin, "A Man-Computer Interface Study for Command and Control Computer Systems," Proc. Int. Conf. Cybernetics and Society, 1979, pp. 21-26.

23. G. H. Walther and H. F. O'Neil, Jr., "On-Line User-Computer Interface: The Effects of Interface Flexibility, Terminal Type, and Experience on Performance," AFIPS Conf. Proc., 1974.

24. J. H. Carlisle, "Man-Computer Interactive Problem Solving: Relationships Between User Characteristics and Interface Complexity," Ph.D. Dissertation, Yale University, 1974 (NTIS AD 786466).

25. S. J. Boies, Unpublished study cited in L. A. Miller and J. C. Thomas, Jr., "Behavioral Issues in the Use of Interactive Systems," Int. J. Man-Machine Studies, 1977.

26. R. B. Miller., "Task Description and Analysis," in R. M. Gagne (ed.), Psychological Principles in System Development, Holt Rinehart and Winston, New York, 1962.

27. T. F. M. Stewart, "The Specialist User," presented at NATO Advanced Study Institute on Man-Computer Interaction, Malfi, Greece, September 1976.

28. J. Rasmussen, Coping with Complexity, RisØ-M-2793 (June 1981).

29. B. Shneiderman, "Human Factors Experiments in Designing Interactive Systems," Computer 12(12), 9-19 (December 1979).

30. B. Shneiderman, Software Psychology, Winthrop Publishers, Inc., Cambridge, 1980.

31. J. Martin, Design of Man-Computer Dialogues, Prentice-Hall, Englewood Cliffs, N.J., 1973.

32. M. Holmgren, Attitudes Towards Computer-Based Communication Devices Within Process Industries, OECD Halden Reactor Project, Rep. HWR-34 (May 1981).

33. R. M. Hanes and J. W. Gebhard, "The Computer's Role in Command Decision," U.S. Naval Institute Proc. 92, 61-68, (September 1966).

34. L. H. Shaffer, "Problem Solving on a Stochastic Process," Ergonomics 8, 181-192, (1965).

35. T. R. Taylor, "The Role of Computer Systems in Medical Decision-Making," in H. T. Smith and T.R.G. Green (eds.), Human Interaction with Computers, Academic Press, New York, 1980.

36. R. L. Weisbrod et al., "Adaptive Computer Aiding in Dynamic Decision Processes," Perceptronics, Rep. PTR-1016-74-11 (November 1974).

37. S. M. Nealey, G. C. Thornton, III, W. S. Maynard, and M. K. Lindell, Defining Research Needs to Insure Continued Job Motivation of Air Traffic Control Systems," NTIS AD-A014-719, Defense Documentation Center, Alexandria, VA, 1975.

38. H. W. Sinaiko, "Human Intervention and Full Automation in Control Systems," Applied Ergonomics, pp. 3-7 (March 1972).

39. R. G. Kinkade and M. P. Ranc, "The Effect of Conflicting Instructions and Feedback Specificity on Tactical Decision Performance," Human Factors 9(3), 257-262 (June 1967).

NUREG/CR-2586
ORNL/TM-8236
Dist. Category RX

INTERNAL DISTRIBUTION

1. J. L. Anderson
2. R. E. Battle
3. G. F. Flanagan
4-7. P. R. Frey
8. D. N. Fry
9. A. M. Fullerton
10. P. M. Haas
11. E. W. Hagen
12-14. R. A. Kisner
15. R. C. Kryter
16. A. L. Lotts
17. F. R. Mynatt
18. L. C. Oakes
19. G. S. Sadowski
20. R. L. Shepard
21. W. H. Sides, Jr.
22. D. B. Trauger
23. Central Research Library
24. Document Reference Section
25-27. Laboratory Records Department
28. Laboratory Records, ORNL RC
29. ORNL Patent Section

EXTERNAL DISTRIBUTION

30. Office of Assistant Manager for Energy Research and Development, U.S. DOE, ORO, Oak Ridge, TN 37830
31. C. L. Hogan, Fairchild Camera and Instrument Corporation, 464 Ellis Street, Mountain View, CA 94040
32-46. J. P. Jenkins, U.S. Nuclear Regulatory Commission, Room 102, Nicholson Lane Building, 5650 Nicholson Lane, Rockville, MD 20852
47. J. V. Leeds, Jr. Professional Engineer, 10807 Atwell, Houston, TX 77096
48. C. A. McKay, Executive Vice President, Corporate Director of Technology, The Foxboro Company, 38 Neponset Avenue, Foxboro, MA 30205
49. O. R. Meyer, Idaho National Engineering Laboratory, Box 1625, Willow Creek Building, Idaho Falls, ID 83415
50. B. M. Oliver, Vice President, Research and Development, Hewlett-Packard Company, 1501 Page Mill Road, Palo Alto, CA 94304
51. H. P. Van Cott, BioTechnology, Inc., 3027 Rosemary Lane, Falls Church, VA 22042
52-53. U.S. DOE Technical Information Center, Oak Ridge, TN 37830
54-463. Given distribution as shown in NRC Category RX