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Simulator Fidelity and Training Effectiveness: A Comprehensive Bibliography with Selected Annotations

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Pacific Northwest Laboratory
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Prepared for
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ABSTRACT

This document contains a comprehensive bibliography on the topic of simulator fidelity and training effectiveness, prepared during the preliminary phases of work on an NRC-sponsored project on the Role of Nuclear Power Plant Simulators in Operator Licensing and Training. Section A of the document is an annotated bibliography consisting of articles and reports with relevance to the psychological aspects of simulator fidelity and the effectiveness of training simulators in a variety of settings, including military. The annotated items are drawn from a more comprehensive bibliography, presented in Section B, listing documents treating the role of simulators in operator training both in the nuclear industry and elsewhere.

TABLE OF CONTENTS

PREFACE

This bibliography was prepared during the preliminary phase of work on the Project on the Role of Nuclear Power Plant Simulators in Operator Licensing and Training within the Safety Technology Program at the Pacific Northwest Laboratory of Battelle for the Human Factors Safety Program of the Nuclear Regulatory Commission. This document contains an annotated bibliography and a more comprehensive bibliography without annotations.

Section A is an annotated bibliography consisting of articles and reports with relevance to issues of the psychological aspects of simulator fidelity and the effectiveness of training simulators. The annotations contain a general summary of the document in terms of the focal industry, the basic objectives of the article or report, and the author(s)' major findings or recommendations which related to our interests. Following the summary are notations on that particular document's treatment of topics related to the determination of simulator fidelity and training effectiveness. The articles were selected to represent a variety of settings in which research on simulators has been carried out, and a variety of perspectives and findings on the appropriateness of simulators for specified training purposes. Many other similar documents exist, but not all could be included. The annotations are structured so as to focus on those questions of most relevance to the project; the annotations do not necessarily represent the entire scope of some of the articles.

Section B is a more comprehensive bibliography of documents treating the role of simulators in operator training, both in the nuclear power industry and elsewhere. A much broader literature was scanned to identify these documents, with these being selected for their relevance to the project and their accessibility.

This body of literature has been used in conjunction with insights and opinions from a panel of experts, from licensing examiners, and from operators, instructors and others in the nuclear power industry in the preparation of NUREG/CR-3725, Nuclear Power Simulators for Operator Licensing and Training. Part I. The Need for Plant-Reference Simulators; Part II. The Use of Plant-Reference Simulators, March 1984.

Section

A

1. SECTION A. ANNOTATED BIBLIOGRAPHY

1.1 LISTING OF ANNOTATED ITEMS

1.2 ANNOTATED ITEMS

Adams, J. A. On the evaluation of training devices. Human Factors, 1979, 21(6), 711-720.

I. GENERAL SUMMARY OF THE DOCUMENT

A. Focal Industry

Aviation industry.

B. Type of Document

Journal article; critique.

C. Basic Objective(s)

To describe and critique methods for evaluating flight simulators for aircrew training.

D. Major Findings or Recommendations

The transfer of training experiment and the experienced operator (pilot) rating methods are the present ways of evaluating the worth of a simulator. The transfer experiment requires the trainee to practice in the simulator and then be tested on the parent operational system to demonstrate the training value of the simulator. The rating method requires the evaluator to be experienced with the parent operational system and to rate the simulator for similarity to the parent system. If similarity is high, the training value is assumed to be high. Arguments are presented that both of these methods are flawed from a scientific methodology point of view. It is contended that a simulator need not necessarily be tested if it is based on reliable scientific principles, and the success of other systems, based on the same principles, has been high. When outcomes can be predicted it is redundant to conduct a system evaluation. The requirement for system testing increases with uncertainty about the principles. Research programs on transfer of training have a payoff because they strengthen the principles of learning and transfer and because they better secure the circumstances under which training devices can be confidently used without necessarily relying on conventional system testing procedures. The psychological principles underlying simulators are reviewed: (1) learning is dependent on error feedback to the trainee; (2) perceptual learning--the increase in the ability to extract information from stimulus patterns as a result of experience; (3) stimulus response learning--the stimulus and the control for response to it must be in the simulator; (4) transfer of training is highest when similarity of the training and transfer situations is the highest; and (5) trainee motivation with the characteristics of the task to be learned as a source of motivation.

II. SIMULATOR TOPIC FOCUS

A. Uses of Simulators Addressed

Training.

B. Types of Simulators Addressed

Low to high fidelity trainers.

III. SIMULATOR FIDELITY

A. Fidelity Dimensions and Definitions

Not addressed.

B. Explicit Statement of Required Fidelity Level

There is a family of relationships between fidelity level and transfer of training. Transfer and fidelity may have a direct relationship but they can also be decoupled with low fidelity also giving high transfer.

C. Variables Affecting Required Fidelity Level

Not specified.

D. Criteria for Determining Required Fidelity Level

Not stated.

E. Methods for Determining Required Fidelity Level

Transfer of training experiment; the rating method.

IV. SIMULATORS IN TRAINING SYSTEMS

A. Relationship to Training for Specified Tasks

Not addressed

B. Relationship to Training Effectiveness

There is reason to believe in the training validity of simulators. The substantiation of this belief depends on the acceptance of the validity of the psychological principles stated to underlie the design and use of simulators. There are examples where use of the simulator has been the only way of successfully acquiring the desired skills, e.g., manned space vehicles.

C. Methods for Establishing Training Effectiveness

Transfer of training experiment; rating method using experienced operators; trainee performance recording and playback devices.

D. Simulators as Part of Training Systems

The simulator is a teaching device and is not any better than the instructor, the instructor's station, and the training syllabus. One cannot talk about the training value of a simulator without including them. The rating method has nothing to say about these factors that are so influential in training operations. Evaluation of the instructor and the training syllabus are implicit in the transfer experiment.

Advisory Group for Aerospace Research and Development. Fidelity of Simulation for Pilot Training. Report No. AGARD AR-159. Neuilly-sur-Seine, France: Advisory Group for Aerospace Research and Development, 1980. (NTIS No. AD-A096 825)

I. GENERAL SUMMARY OF THE DOCUMENT

A. Focal Industry

Flight industry.

B. Type of Document

Report of working group review of literature and practices. Descriptive article.

C. Basic Objective(s)

Basic purpose of the paper was to report the results of an AGARD study on the scope and effectiveness of current flight training in simulators, the status of technologies and human behavior important to the fidelity of flight simulation, and need for research in the areas of simulation technologies and training that might lead to increased cost-effectiveness in simulator training.

D. Major Findings or Recommendations

Findings were reported by subgroups focused on pilot training, physiological factors, and simulator technology. The unifying topic was simulator fidelity in relation to pilot training. The following steps were suggested for developing simulator facilities: (1) analyze training objectives; (2) define training methods and facilities (this is difficult, and includes definition of objective and perceptual cues experienced in the aircraft and in training, as well as definition of hardware needed to provide the cues); (3) develop simulator hardware; (4) validate simulator (this includes performance of objective tests and training effectiveness tests, followed by a repeat of steps 1 through 4 until satisfactory transfer of training is attained).

Technology is deficient in some aspects of definition of perceptual cues experienced by pilots in aircraft. However, there are data in the literature which USAF HRL is putting into a more usable form, due in 1982.

There are hardly any generalizable data on perceptual cues needed in training. Research is needed, and is a prerequisite to specification of hardware. It would be useful to develop measures of training effectiveness other than the Transfer Effectiveness Ratio (TER); they should be more comprehensive and should take into account cost-effectiveness.

II. SIMULATOR TOPIC FOCUS

A. Uses of Simulators Addressed

Training, retraining, license examination. These uses may not be compatible. For example, high physical and dynamic fidelity are required by FAA for license exam purposes; training, on the other hand, may be possible with much simpler devices.

B. Types of Simulators Addressed

Full-scale, part-task; dynamic

III. SIMULATOR FIDELITY

A. Fidelity Dimensions and Definitions

"Objective fidelity provides an engineering viewpoint and is the degree to which a simulator would be observed to reproduce its real-life counterpart aircraft, in flight, if its form, substance, and behavior were sensed and recorded by a nonphysiological instrumentation system onboard the simulator. By including both equipment and environmental cues, this definition can encompass all pertinent dynamic cue timing and synchronization aspects of simulator fidelity."

"Perceptual fidelity provides a psychological/physiological viewpoint and is the degree to which the trainee subjectively perceives the simulator to reproduce its real-life counterpart aircraft, in flight, in the operational task situation. The requirement that the operational equipment be considered in the context of the task situation ensures that not only cue timing and synchronization, but also cue priority effects, are taken into account."

"Equipment cues provide a duplication of the appearance and feel of the operational equipment."

"Environment cues provide a duplication of the environment and motion through the environment."

B. Explicit Statement of Required Fidelity Level

It is not always true that high fidelity results in better training. There is "no unique answer to the question of how much fidelity is required--or the best--for training a given task." For each task to be trained, information must be provided as to relevant conditions under which it will be performed, cueing information necessary, procedures of task, and criteria for determining if task is successfully completed. This information can be used to develop training objectives, which determine level of fidelity needed. The level will vary from task to task.

C. Variables Affecting Required Fidelity Level

See III-B. Variables include nature of task, student experience, proficiency level being trained.

D. Criteria for Determining Required Fidelity Level

Specific cues (equipment or environmental) should be simulated only if necessary for fulfillment of training objectives. In some areas high objective fidelity is crucial to perceptual fidelity; inadequacy in even a small detail may significantly decrease perceived fidelity (several aircraft examples given).

E. Methods for Determining Required Fidelity Level

For each type of cue (equipment and environmental), determine how much perceptual fidelity is required for satisfactory training. Then assess the amount of objective fidelity needed for the specified level of perceptual fidelity.

IV. SIMULATORS IN TRAINING SYSTEMS

A. Relationship to Training for Specified Tasks

Pilot training.

B. Relationship to Training Effectiveness

Training effectiveness is determined not only by the qualities of the simulator, but by the particular uses of it. Effectiveness may improve with a change in use. Studies have shown that simulation is most effective when students are given unlimited time on the simulator.

Differences between simulator and operating equipment may be necessary for greatest training effectiveness. For example, training effectiveness may increase with: decreased level of complexity of instrument; provision of knowledge of results; decrease in stress of initial training environment.

Simulator training studies often show high levels of proficiency in the critical period immediately upon transfer from simulator to aircraft.

C. Methods for Establishing Training Effectiveness

Ten training effectiveness models were reviewed:
Transfer-of-Training, Self-Control Transfer, Pre-existing Control

Transfer, Uncontrolled Transfer, Simulator-to-Simulator Transfer, Backward Transfer, Simulator Performance Improvement, Simulator Fidelity, Simulator Training Program Analysis, and Opinion Survey. The pilot opinion survey method is often used, but it is not necessarily a good measure of training effectiveness. Likewise, assessments of fidelity or of overall utilization are questionable indicators. The most appropriate assessment methods are those based on the transfer of training (TOT) model. (Transfer of training "occurs whenever the existence of a previously learned behavior and skill has an influence on the acquisition, performance, or relearning of a second behavior or skill.")

The Transfer Effectiveness Ratio (TER) is a possible measure of TOT (TER is the ratio of number of aircraft--or power plant--hours saved to the number of hours required in the simulator. Thus, a TER of 1.0 would indicate simulator training effectiveness equivalent to actual equipment effectiveness). In practice, it is difficult to devise and implement appropriate measures of simulator training effectiveness. This is partly because it is hard to measure learning achieved in the simulator, learning which transfers to the actual equipment, and extent of savings made.

D. Simulators as Part of Training Systems

Simulators are just part of the training system; their interdependence with other aspects of training is often ignored, but it should not be.

Angell, D., Shearer, J., & Berliner, D. Study of Training Performance Evaluation Techniques. Technical Report NAVTRADEVCEN-1449-1. Port Washington, NY: Naval Training Device Center, October 1964. (NTIS No. AD-609 605)

I. GENERAL SUMMARY OF THE DOCUMENT

A. Focal Industry

Military.

B. Type of Document

Literature review and position paper on performance evaluation.

C. Basic Objective(s)

The report discusses performance evaluation during training, specifically training using simulators and other complex training equipment. The important variables involved in developing a system of performance evaluation measurements are seen to be (1) types of behaviors; (2) types of measurements or indices; and (3) types of instruments for performance recording. Factors related to these variables are discussed. An illustrative application of an automatic training/evaluation system is presented. The report concludes that automated systems of performance measurement in training situations using simulators appear to offer a number of advantages: (1) more objective measures are provided than by fallible human observers, and with an increase in objectivity, all of the purposes of performance measurement are more directly and accurately fulfilled; (2) automatic equipment is capable of providing more detailed performance information; (3) evaluations can be made very rapidly; and (4) training equipment may be used to its maximum capability.

D. Major Findings or Recommendations

The value of measures provided by automatic monitors depends on (a) use of standard problems, run under comparable sets of circumstances; and (b) availability of valid criterion data on performance. The success of performance evaluation depends not only on the precision of measurement but more basically on the measurement of the relevant and important behaviors identified through careful and thorough task and mission analyses. Performance evaluation capabilities ought always to be an important consideration in the design of training systems.

II. SIMULATOR TOPIC FOCUS

A. Uses of Simulators Addressed

Training for military systems use, learning a task, improving performance, testing performance.

B. Types of Simulators Addressed

Full- and part-task simulators.

III. SIMULATOR FIDELITY

A. Fidelity Dimensions and Definitions

Not specifically addressed.

B. Explicit Statement of Required Fidelity Level

For some missions--those which are complicated and hazardous and which require highly developed skills--it is essential that the transfer from the training environment to the operational environment be perfect. First-of-a-kind spaceflights are dramatic examples of this situation. Much of the credit for success must go the high fidelity simulation devices used.

C. Variables Affecting Required Fidelity Level

Types of behaviors to be taught, types of performance measurements to be taken.

D. Criteria for Determining Required Fidelity Level

Not addressed.

E. Methods for Determining Required Fidelity Level

Not addressed.

IV. SIMULATORS IN TRAINING SYSTEMS

A. Relationship to Training for Specified Tasks

Choice of and use of simulator depend upon specific task analysis.

B. Relationship to Training Effectiveness

Simulators have capability of both training and evaluating performance. The simulator permits a firmer exercise of control over measurement conditions and closer standardization of the testing environment. The reliability of performance measures is a function of controlled measurement conditions. There are three general time periods during which it is most sensible to obtain measures of performance proficiency--before training, during training, and after training.

C. Methods for Establishing Training Effectiveness

Comparison of performance proficiency between experimental and control groups.

D. Simulators as Part of Training System

Simulator can be used as both trainer and evaluator. Uses have to be integrated into total training program.

Caro, P. W. Some Current Problems in Simulator Design, Testing and Use. Report No. HumRRO-PP-2-77. Alexandria, VA: Human Resources Research Organization, 1977. (NTIS No. AD-A043 240)

I. GENERAL SUMMARY OF THE DOCUMENT

A. Focal Industry

Military (Air Force).

B. Type of Document

Symposium paper dealing with simulator training research projects sponsored by Army, Navy, Air Force, and Coast Guard.

C. Basic Objective(s)

Principal focus of paper is the identification of problems related to simulator design, testing, and uses that have an impact on simulator training effectiveness.

D. Major Findings or Recommendations

Eight problems with existing simulator training are described: (1) isolation of simulator user from its design and development; (2) inattention by simulator designers to behavioral and training models; (3) ignoring of training considerations and actual training utility during simulator acceptance testing; (4) inadequate feedback to simulator designers concerning simulator training effectiveness and experiences; (5) inattention to techniques of simulator training that differ from techniques of real system training; (6) inadequate training for simulator instructors; (7) use of rate of simulator utilization as an index of training effectiveness; and (8) inadequacies of simulator cost-effectiveness data due to lack of information of training effectiveness.

These problems are related to the fact that simulator training is not seen in a broad training context but in simulator design, testing, and use; all training components, simulators, operational systems, classroom attendance must be considered as a whole.

II. SIMULATOR TOPIC FOCUS

A. Uses of Simulators Addressed

Training, instructor's uses.

B. Types of Simulators Addressed

Full-scope simulators (aircraft, weapons).

III. SIMULATOR FIDELITY

Not addressed.

A. Fidelity Dimensions and Definitions

Not addressed.

B. Explicit Statement of Required Fidelity Level

Not addressed.

C. Variables Affecting Required Fidelity Level

Not addressed.

D. Criteria for Determining Required Fidelity Level

Not addressed.

E. Methods for Determining Required Fidelity Level

Not addressed.

IV. SIMULATORS IN TRAINING SYSTEMS

A. Relationship to Training for Specified Tasks

Not addressed.

B. Relationship to Training Effectiveness

Author points out that the relationship is not known leading to misuse of the simulator. An Air Force example is quoted of perceived overuse.

C. Methods for Establishing Training Effectiveness

Not addressed.

D. Simulators as Part of Training Systems

Stresses need to integrate simulator use into a well-planned, systematically developed training program.

Collins, P. F. Reactor operator training programs utilizing nuclear power-plant simulators. Nuclear Safety, 1975, 16(4), 482-488.

I. GENERAL SUMMARY OF THE DOCUMENT

A. Focal Industry

Nuclear power industry.

B. Type of Document

Descriptive.

C. Basic Objective(s)

The article is explicitly about the use of simulators for nuclear power-plant training. The document describes the NRC licensing process and requirements and surveys the use of simulators for training.

D. Major Findings or Recommendations

The NRC requires that all operators of the controls of nuclear facilities be licensed. License applicants must pass NRC written examinations and operating tests. Operating experience may be obtained through approved training programs utilizing simulators. Accepted training programs, given by power-plant systems vendors, include: (1) nuclear fundamentals course; (2) research-reactor operation; (3) lectures on nuclear power-plant design; (4) observations at operating plants; and (5) simulator operations.

Acceptable simulator use is limited to personnel from facilities whose control rooms are closely copied by the simulator. The NRC also requires already licensed individuals to participate in requalification programs that require licensees to manipulate reactor controls through a specified number of evolutions during their license tenures. If the simulator's operating characteristics and control room are similar to those of the applicant's facility, manipulation of simulator controls is permitted so that the number of plant evolutions solely for requalification can be minimized. The NRC has found that individuals trained on simulators have a better understanding of plant responses to transient conditions and abnormal situations and are also more confident in answering questions requiring prediction of plant responses to postulated situations. Simulators are extremely effective for examining an evaluating individuals. The NRC believes that simulators, used in conjunction with comprehensive training programs, are effective training devices and intends to encourage their use in future training programs.

II. SIMULATOR TOPIC FOCUS

A. Uses of Simulators Addressed

Training, requalification, license examinations.

B. Types of Simulators Addressed

High-fidelity, full-scale simulators.

III. SIMULATOR FIDELITY

A. Fidelity Dimensions and Definitions

Not addressed.

B. Explicit Statement of Required Fidelity Level

Simulator should reproduce the general operating characteristics of the trainee's facility and have an instrumentation and control arrangement similar to that of the facility.

C. Variables Affecting Required Fidelity Level

Number of systems simulated, degree of simulation, number and types of malfunctions used for training, simulator's response compared to that of actual plant, comparison of simulator with information in final safety-analysis facility report, competency of training staff.

D. Criteria for Determining Required Fidelity Level

Not presented.

E. Methods for Determining Required Fidelity Level

Not addressed.

IV. SIMULATORS IN TRAINING SYSTEMS

A. Relationship to Training for Specified Tasks

Tasks required for licensing examinations.

B. Relationship to Training Effectiveness

Simulators extremely effective for examining and evaluating individuals. Individuals trained on simulators have better understanding of plant responses and display greater confidence in predicting plant responses.

C. Methods for Establishing Training Effectiveness

Scientific estimation or analysis of training transfer or effectiveness not reported.

D. Simulators as Part of Training Systems

Simulator use part of training program together with classroom teaching and actual plant operation.

Crawford, M. P. Dimensions of simulation. American Psychologist, 1966, 21(8), 788-796.

I. GENERAL SUMMARY OF THE DOCUMENT

A. Focal Industry

Military and others; nuclear industry not explicitly covered.

B. Type of Document

Descriptive article.

C. Basic Objective(s)

The article describes major uses of simulation, focusing on simulation for training and on measurement of its results. Perceptual structuring of environments in relation to occupations is discussed. Psychological dimensions of simulation are suggested.

D. Major Findings or Recommendations

The article examines simulation from the point of view of research and development in training. Simulation is first discussed generally. Two taxonomies for simulation are proposed. The first classification is in system terms: in simulations of open-loop systems, humans do not control environmental variables, whereas in simulations of closed-loop systems, some control is exerted over the environment. A second taxonomy is based on the purposes of simulation. Purposes include design, training and testing, or combinations of these.

Open-loop environmental simulation with human participation can be used to test human performance in strange environments. In general, variables that can be measured (e.g., temperature, pressure, illumination) can also be reproduced in simulation, and their effects on human performance can be assessed. By contrast, variables that can not be measured (e.g., cognitive maps), can not be reproduced and assessed.

Simulation that does not involve people often includes some representation of human functions (e.g., sensory, motor). More and better data are needed to allow development of accurate representations. Such simulation can help determine which aspects of human performance in man-machine systems would, if improved, lead to greatest increase in system output.

The remainder of the paper concerns issues in simulation for training and outcome measurement. To design good simulators, it is necessary to analyze the occupations for which they train. Patterns of selective perception and more or less uniform responses are characteristic of specific occupations. The function of training is to teach these patterns of behavior.

There are two extreme cases of initial training: classroom learning, in which representation of the work environment is symbolic, and apprenticeship, in which the learner is placed in a (usually somewhat sheltered and monitored) work setting. Increasingly, simulation is being used in the classroom situation.

Considerable research has been done on ways of representing interactions between operational equipment and unfamiliar environments (e.g., for astronaut training). Full-scale simulation is invariably used.

Miniaturization is a simulation technique that has been used with some success. For example, transfer of training has been shown from the Miniature Armored Battlefield and the Combat Decisions Game. Miniaturization allows the learner to form a more global cognitive map than would be possible from within the large operational situation.

The main issue in simulation that emphasizes interactions between people, is cognition. Purposes of simulation include attitude change and behavior modification. Simulation may involve discussion and role playing. Learning in this area is difficult to measure.

In simulation for proficiency measurement, the key issue is the cognitive state of the subject. It is important that the subject be fully involved with the simulation, and that aspects such as stress be adequately represented; unfortunately, both conditions are unlikely.

Dimensions of simulation are proposed to be: (1) extent of represenation of environment; (2) length of experience provided by simulator; (3) extent of mediacy between human and environment; (4) importance of interpersonal relations; and (5) amount of cognitive involvement.

II. SIMULATOR TOPIC FOCUS

A. Uses of Simulators Addressed

Design, Training, Testing.

B. Types of Simulators Addressed

Full-scale, part-task, dynamic.

III. SIMULATOR FIDELITY

A. Fidelity Dimensions and Definitions

Not addressed.

B. Explicit Statement of Required Fidelity Level

"Procedural trainers [are used in aviation training] . . . as means for the learner to impose structure on the environment. A long list of studies have shown that the simulation for this purpose does not need to be of high fidelity, at least when time sharing is not a problem . . . a 92-step procedure at a missile launcher control panel can be learned as well with a small-sized drawing as with a fully operational simulator.

C. Variables Affecting Required Fidelity Level

Nature of interaction between operational equipment and environment (complexity of control feedback).

D. Criteria for Determining Required Fidelity Level

Not addressed.

E. Methods for Determining Required Fidelity Level

Not addressed.

IV. SIMULATORS IN TRAINING TASKS OR SYSTEMS

A. Relationship to Training for Specified Tasks

Not addressed.

B. Relationship to Training Effectiveness

Not addressed.

C. Methods for Establishing Training Effectiveness

Not addressed.

D. Simulators as Part of Training Systems

". . . it has long been apparent to us in the Human Resources Research Office (HumRRO) that effective training programs can be devised only from a careful analysis of the system in which the graduate will take his place."

Cream, B.W., Eggemeier, F. T., & Klein, G. A. A strategy for the development of training devices. Human Factors, 1978, 20(2), 145-158.

I. GENERAL SUMMARY

A. Focal Industry

U.S. Air Force.

B. Type of Document

Description of methods for evaluation.

C. Basic Objective(s)

The paper discusses the complex issues involved in the design of aircrew simulation training devices. It addresses methods for defining training requirements, fidelity performance measurement, instructional features, crew coordination, and user acceptance. A research evaluation of a device using these methods is presented. The basic strategy for simulator design consists of defining precise training requirements, identifying supporting features and preparing a utilization plan as early as possible in the development cycle. Three groups can provide essential inputs to simulator design: the instructors, the training psychologists and the simulation engineers. The major issues are the selection of tasks to be trained and the degree of simulation fidelity to accomplish the required training. Task ranking by criticality, frequency of performance and difficultly of performance provide data necessary for required fidelity decisions, serve as a basis for performance measurement and instructor station design requirements. Determination of performance measurement capabilities also help to define the instructor's station and ability to observe and collect performance data. The instructor's station must support the performance of four functions: (1) controlling and setting up of tasks; (2) measuring trainee's performance; (3) displaying and recording these measurements on a useful form; and (4) presenting these measurements and other instructional communications as feedback to the student. Previous efforts in crew training have concluded that in order to provide adequate crew familiarization training, the contingencies and normal operating modes used in training devices must include appropriate operator task loadings in real time. Careful attention must be paid to the capabilities and qualifications of the instructors and to the quality of the operator manuals for the training device.

D. Major Findings or Recommendations

The conclusions of the experiment reported were that the groups of subjects trained on the device reached consistent criterion performance in less time than their control groups. At the completion of training a greater percentage of subjects trained on the device received "completely qualified" ratings than did the control subjects. On the basis of the evaluation, it could be concluded that the design of a training device according to the presented strategy did produce an effective device well accepted by its users.

II. SIMULATOR TOPIC FOCUS

A. Uses of Simulator Addressed

Training, crew coordination.

B. Types of Simulator Addressed

Part-task/full-scale training devices.

III. SIMULATOR FIDELITY

A. Fidelity Dimensions and Definitions

Functional Fidelity--faithful duplication of all stimulus conditions. Partial fidelity.

B. Explicit Statement of Required Fidelity Level

Level of fidelity needed to accomplish specific tasks can be roughly estimated in terms of required cues and the required clarity of their presentation.

C. Variables Affecting Required Fidelity Level

Costs of obtaining various levels of fidelity can be discussed in terms of dollars, limitations in the state-of-the art, and reliability difficulties. No rigorous decision-making procedures have been developed here. The factors in the cost/capability tradeoff are not easily quantified.

D. Criteria for Determining Required Fidelity Level

Differentiation of essential from non-essential aspects of the controls and displays to insure that only the required fidelity is provided. The training device design team attempts to identify all the negative consequences of deleting each type of information and then estimate the probability and criticality of these consequences.

E. Methods for Determining Required Fidelity Level

See III-C, D. Experienced personnel should continually validate the adequacy of the display characteristics, control "feel," scenario integration and other general fidelity issues.

IV. SIMULATORS IN TRAINING SYSTEMS

A. Relationship to Training for Specified Tasks

Simulator design tied to its specific training use.

B. Relationship to Training Effectiveness

Tested training devices found to be effective. Criterion used was number of flying training missions to consistent criterion for each subject.

C. Methods for Establishing Training Effectiveness

Performance rating by instructor pilots. These are not the same instructors used for training devices.

D. Simulator as Part of Training System

Development of training devices should be guided by training requirements determined by task analysis. There is a need for a systematic methodology to match training device features with training requirements.

Crosby, J. V., Pohlmann, L. D., Leshowitz, B., & Waag, W. L. Evaluation of a Low Fidelity Simulator (LFS) for Instrument Training. Report No. AFHRL-TR-78-22. Brooks Air Force Base, TX: HQ Air Force Human Resources Laboratory, 1978. (NTIS No. AD-A058 139)

I. GENERAL SUMMARY OF THE DOCUMENT

A. Focal Industry

U.S. Air Force.

B. Type of Document

Technical report, primary research.

C. Basic Objective(s)

Basic objective of the research was to investigate the transfer of training from a low fidelity simulator to a higher fidelity device, and subsequently to an aircraft. An attempt was made to determine both the magnitude and the temporal duration of the transfer effect.

D. Major Findings or Recommendations

On the initial evaluation, the low fidelity simulator trained group performed significantly better when tested and adapted more quickly to the higher level simulator. However, once both experimental and control groups had been trained on the higher level simulator, no differences were found for performance on the actual aircraft. The results indicated a considerable amount of positive transfer at the outset, but the initial performance differences disappeared after one month of academic and higher level simulator experience. These observations were contrary to expectations. Explanations for the unexpected observations include performance ceilings, simulator stress versus actual system stress for the trainee, interaction of simulator fidelity, and quality of instructor-trainee interaction.

II. SIMULATOR TOPIC FOCUS

A. Uses of Simulators Addressed

Training

B. Types of Simulators Addressed

Low-fidelity, modest-fidelity, part-task and advanced, state-of-the-art whole-task high fidelity simulators.

III. SIMULATOR FIDELITY

A. Fidelity Dimensions and Definitions

Not addressed.

B. Explicit Statement of Required Fidelity Level

Not given; defined by existing simulators used for the experiment.

C. Variables Affecting Required Fidelity Level

Transfer of training effectiveness.

D. Criteria for Determining Required Fidelity Level

Transfer of training effectiveness, performance on real system.

E. Methods for Determining Required Fidelity Level

Transfer of training and real system performance experiments using experimental and control groups.

IV. SIMULATORS IN TRAINING SYSTEMS

A. Relationship to Training for Specified Tasks

Low and modest fidelity part-task simulators may fail to provide realistic simulated practice for more difficult part and whole task maneuver skills.

B. Relationship to Training Effectiveness

Results unclear.

C. Methods for Establishing Training Effectiveness

Performance criteria measurements on simulators and actual craft evaluation based on mean number of trials to reach criterion level of performance.

D. Simulators as Part of Training Systems

Transfer of training studies need to investigate interactive roles of student, instructor, and training device as a system rather than focusing exclusively on the simulator.

Erwin, D. C. (Ed.). Psychological Fidelity in Simulated Work Environments. Report No. ARI-RES Problem Rev-78-26. Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences, 1978. (NTIS No. AD-076-658)

I. GENERAL SUMMARY OF THE DOCUMENT

A. Focal Industry

Military.

B. Type of Document

Collection of four papers presented at a symposium (see Section V of this entry for list of papers).

C. Basic Objective(s)

State-of-the-art reviews of data, methods, and theory.

D. Major Findings or Recommendations

The basic issue is the relationship between fidelity, training effectiveness, and performance. How does the training designer find the level of physical fidelity to achieve an acceptable level of psychological fidelity to elicit behaviors or performance levels specified as training objectives. The general findings are that the data are insufficient, the methods inadequate, and the theory undeveloped for answering the question.

II. SIMULATOR TOPIC FOCUS

A. Uses of Simulators Addressed

Individual and team training.

B. Types of Simulators Addressed

Full-scope, part-task.

III. SIMULATOR FIDELITY

A. Fidelity Dimensions and Definitions

Psychological fidelity defined as the relative psychological contiguity of actual and simulated stimulus environments. Psychological fidelity same as behavioral fidelity. Transfer-of-training discrepancy factor is defined to be the difference in probabilities for the simulated and actual situation that a specified set of responses will be elicited by a set of stimuli. Psychological fidelity is inversely related to the transfer-of-training discrepancy factor (TOTDF). TOTDF is an indication of the extent to which the set of actual stimuli approximates the set of stimuli that occur in the simulated environment and which are known to elicit the target responses with some probability determined during training.

B. Explicit Statement of Required Fidelity Level

As soon as the capabilities of a simulator support the practice of a set of training tasks, stop adding to it. No specific level of fidelity stated.

C. Variables Affecting Required Fidelity Level

Individual variation in responses to training; transfer-of-training discrepancy factor; type of situation to be simulated: established with specifiable conditions and predictable consequences or emergent with unpredictable conditions and consequences; human behavior model used: stimulus-response or organismic. Emergent situations and organismic model require increased fidelity.

D. Criteria for Determining Required Fidelity Level

Task analysis based on criticality, frequency, and difficulty ratings. Can lead to decisions on required fidelity for controls and visual displays. Other criteria include simulator cost, reliability, and maintainability.

E. Methods for Determining Required Fidelity Level

Measurements made on experienced operator doing real task for eventual comparison with measurements made on trainee at the simulator. Use of adjustable fidelity level simulators to match different training situations.

IV. SIMULATORS IN TRAINING SYSTEMS

A. Relationship to Training for Specified Tasks

Established situation simulation is different from emergent situation simulation. Psychological fidelity important for man-ascendant systems, physical fidelity important for machine-ascendant systems.

B. Relationship to Training Effectiveness

Too much fidelity can impair training effectiveness through overloading trainee's attention and through improper sequencing of tasks to be mastered. Increased physical fidelity was shown by experiments not to be necessarily related to increased training effectiveness.

C. Methods for Establishing Training Effectiveness

Pilot ratings, time to adapt to real system, performance at simulated and real systems.

D. Simulators as Part of Training Systems

Need to be integrated, linked to systematic development of training objectives.

V. REPORTS INCLUDED IN THE SYMPOSIUM

Alluisi, E. A., Discussant, discussion of psychological fidelity in simulated work environments.

Eddowes, E. E., Flight simulator fidelity and flying training effectiveness.

Eggemeier, F. T., & Cream, B. W., Some considerations in the development of team training devices.

Erwin, D. E., Engagement simulation training systems: Simulation training in collective, man-ascendant tactical environments.

Harris, Frank J., Introduction to the symposium.

Matheny, W. C., The concept of performance equivalence in training systems.

Fink, C. D., & Shriver, E. L. Simulators for Maintenance Training: Some Issues, Problems and Areas for Future Research. Report No. AFHRL-TR-78-27. Alexandria, VA: Kinton, Inc., 1978. (NTIS No. AD-A060 088)

I. GENERAL SUMMARY

A. Focal Industry

Military.

B. Type of Document

Technical report; literature review, and future research recommendations.

C. Basic Objective(s)

The article focuses on technical training. Literature on maintenance training use of simulators is reviewed.

Emphasis is on describing issues, problems and future research areas as identified by recent authors. Topics discussed include: application of simulation technology to technical training, cost-effectiveness of low-fidelity aids, identification of tasks to be simulated, selection of simulation requirements, relationship between simulation requirements, learning stages and transfer of training, issue of functional/physical fidelity, incorporation of instructional features, procedures for developing specifications, problem of obtaining instructor and student acceptance of the simulator.

D. Major Findings or Recommendations

The reviewers note that the current issues and problems are similar to those that have been asked for twenty years. Principal conclusions were that: (a) large field scale studies are needed to demonstrate whether or not training based on maintenance simulators actually does transfer to the real job; (b) development of exemplary training programs; (c) development of exemplary simulators; (d) investigation of procedures to identify training requirements which could be supported by simulators, tasks to be simulated and instructional features to be incorporated; (e) exploration of techniques for obtaining user acceptance, especially that of instructors and key administrative personnel; (f) comparative evaluation of simulators to determine relative advantages and disadvantages; and (g) development of improved regulations on who the simulation acquisition decisionmakers and resource groups should be, and what improved guidance should be provided to these persons.

II. SIMULATOR TOPIC FOCUS

A. Uses of Simulators Addressed

Equipment maintenance training.

B. Types of Simulators Addressed

Training aids, part-task, whole task, familiarization, constructed response, and automated skills trainers.

III. SIMULATOR FIDELITY

A. Fidelity Dimensions and Definitions

Three types of fidelity relevant to training devices:

1. Physical or equipment fidelity refers to the extent to which training equipment duplicates the appearance and feel of the real equipment.

2. Functional or environmental fidelity refers to the extent to which training equipment duplicates stimuli which are present in the operational environment and provides an opportunity for responding realistically to these stimuli.

4. Psychological fidelity refers to the extent to which trainees perceive the training equipment as being a duplicate of the operational equipment and the task situation.

B. Explicit Statement of Required Fidelity Level

There is widespread agreement that to be effective a training device should possess a high degree of functional fidelity. There is considerable disagreement over the amount of physical fidelity a training device should have.

C. Variables Affecting Required Fidelity Level

Difficulty, frequency and importance of the task to be trained.

D. Criteria for Determining Required Fidelity Level

See III-C.

E. Methods for Determining Required Fidelity Level

Use of experimental and control groups to compare simulator and non-simulator exposure on performance.

IV. SIMULATORS IN TRAINING SYSTEMS

A. Relationship to Training for Specified Tasks

The evidence seems convincing. Simulators are more cost-effective for teaching malfunction location techniques than are actual equipment trainers; low-cost, low-fidelity mock-ups for teaching nomenclature, parts location and procedures may be more cost-effective than more expensive real equipment trainers. Once training requirements have been identified there is still a need to select the tasks to be simulated. Tasks are ranked according to difficulty, frequency, and importance. The highest ranked tasks are then considered for simulation and the level of fidelity.

B. Relationship to Training Effectiveness

Transfer of training should be viewed with reference to stages of learning. Acquiring enabling knowledge and skills; acquiring uncoordinated skills and applicable knowledges; acquiring coordinated skills and ability to apply knowledge; acquiring acceptable job proficiency. A well designed training sequence seeks to maximize positive transfer from one stage to another. Different kinds of tasks and different stages of learning have different implications for transfer of training but we still do not know enough about these relationships.

C. Methods for Establishing Training Effectiveness

Comparison of performance of experimental and control groups.

D. Simulators as Parts of Training Systems

Training aids are used early in the learning process to decrease time and effort required to acquire skills and knowledges later on. Part-task trainers are used so that trainees spend less time on job-segment or whole-task trainers. Whole-task trainers are used when it is necessary to reduce the amount of time required to obtain acceptable on-the-job proficiency. Obviously, no one class of training aid need carry the entire training load. From a cost-effectiveness standpoint, the general training strategy should be to use training devices that can support the first and second learning stages before switching to the more expensive simulators required to support later learning stages. It might be true that more sophisticated higher-fidelity trainers have the capability of teaching what might be taught by less advanced trainers. However, time thus spent would be taken away from that time advanced students could be making more appropriate use of the advanced trainer. There has been an increased realization that the effectiveness of training devices depends on how they are used and accepted by instructors and students. Instructors are the more important because they are in a position to defeat the purpose of the training devices and to govern the attitude of the trainees towards these devices. Instructors should have the final say with respect to the design of the simulator and should be responsible for preparing the plan for integrating the device into the training program.

Gagné, R. M. Training devices and simulators: Some research issues. American Psychologist, 1954, 9, 95-107.

I. GENERAL SUMMARY OF THE DOCUMENT

A. Focal Industry

The article considers training devices from a psychological point of view; most examples given are military.

B. Type of Document

Descriptive article.

C. Basic Objective(s)

The purpose of the article is to describe some areas of needed psychological research related to development, use, and evaluation of training devices.

D. Major Findings or Recommendations

There are two major uses of training devices: performance evaluation and performance improvement. Different device characteristics are necessary for these two purposes, although the same device is often employed for both. Reliability and validity are the crucial characteristics of a training device used for performance evaluation. Transfer of training to operational equipment is the key characteristic of a training device used for performance improvement. In both cases, fidelity of simulation is of secondary importance.

Much research is needed to answer questions about training device development, use, and evaluation.

II. SIMULATOR TOPIC FOCUS

A. Uses of Simulators Addressed

Performance measurement; performance evaluation.

B. Types of Simulators Addressed

Full-scale; part-task.

III. SIMULATOR FIDELITY

A. Fidelity Dimensions and Definitions

The term "fidelity" is not used. However, a "simulator" is defined as a "training device which has a high degree of resemblance to operational equipment, particularly with respect to the display, the controls, and the way one affects the other when in operation." This definition incorporates the ideas of physical and functional fidelity.

B. Explicit Statement of Required Fidelity Level

When training devices are used for performance measurement, their most important characteristics are reliability and validity. The two qualities both affect need for fidelity--sometimes in a conflicting manner. "Even assuming that high degrees of similarity are desirable for validity, sacrifices at the expense of similarity must often be made for the sale of reliability of performance measurement." For example, reliability depends on obtaining an adequate sample of the behavior being measured; training devices may have to differ from operational equipment to provide such a sample.

When training devices are used for performance improvement, their key characteristic is amount of transfer of training. Effectiveness of training may be increased by designing a training situation which differs from the job situation by giving extensive practice on critical component skills, rather than on the full task.

C. Variables Affecting Required Fidelity Level

For training purposes: adequate representation of critical task skills; effect of fidelity on learning of skills and on transfer of training.

For performance measurement purposes: effect of fidelity on reliability and validity.

D. Criteria for Determining Required Fidelity Level

"The question of how closely a device should be made to simulate an operational situation can often be reduced to the question of critical skills."

E. Methods for Determining Required Fidelity Level

The first step is to do an analysis of the task to be trained. This includes categorizing specific equipment-oriented behaviors and skills of the task, and determining which of these are critical.

For performance measurement devices, it is also necessary to select performance criteria; this will permit determination of which characteristics of the task must be simulated to give high validity. "There is little evidence, and no theory, which enables a choice of the most desirable criterion measurement, except on the basis of reliability."

IV. SIMULATORS IN TRAINING SYSTEMS

A. Relationship to Training for Specified Tasks

Not addressed.

B. Relationship to Training Effectiveness

". . . the answer to the problem of what makes a training device effective is to be sought, not in identity of all task elements, but rather in viewing a training device as a means of making conditions most effective for learning."

Often it is best to alter the training device situation from the operational situation. Issues that should be considered in design of simulation for training are repeated practice, motivation and reinforcement (including knowledge of results and frequency of reinforcement), learning set, component practice, response precision (including enforced guidance), and performance feedback (including frequency and size of chunks of information).

C. Methods for Establishing Training Effectiveness

Controlled learning experiments are the means of measuring the difference between performance on task preceded by practice on training device, and performance on task not preceded by such practice. The experiments are often very difficult for many reasons, including lack of adequate criterion performance measures.

Although this will not indicate transfer of training, a partial evaluation may be obtained by measuring improvement in performance on the training device itself.

D. Simulators as Part of Training Systems

It is important to have a field evaluation of the training device. This evaluation should determine what are the conditions that give most effective use of the device.

Gerathewohl, S. J. Fidelity of Simulation and Transfer of Training: A Review of the Problem. Report No. FAA-AM 69-24. Washington, DC: Federal Aviation Administration, 1969. (NTIS No. AD-706 744)

I. GENERAL SUMMARY OF THE DOCUMENT

A. Focal Industry

U.S. Air Force.

B. Type of Document

Document is a technical report which reviews and summarizes relevant research projects.

C. Basic Objective(s)

Basic document objective is to review existing literature on the influence of fidelity of simulation on pilot performance.

D. Major Findings or Recommendations

General conclusions are that the amount of transfer expected to occur in flight simulators seems to be proportional to the degree of fidelity provided. However, part-task simulators can be very useful for learning specific tasks. The various perceptual phenomena, physiological effects, and performance changes observed in complex simulators indicate that it is the psychologic, physiologic, and operational realism which determine simulation fidelity, not the mere physical similarity of the devices. Two additional factors are motivation and danger (stress). However, NASA experience seems to indicate that danger is not a necessary prerequisite for the transfer of training. A general scientific theory which accurately predicts the optimum degree of fidelity needed to achieve maximum transfer of flight training has still to be developed.

II. SIMULATOR TOPIC FOCUS

A. Uses of Simulators Addressed

Training, human factors research, proficiency measurements.

B. Types of Simulators Addressed

Full-scope, part-task flight simulators.

III. SIMULATOR FIDELITY

A. Fidelity Dimensions and Definitions

"Fidelity" is defined as the degree to which a device accurately reproduces a specific effect.

B. Explicit Statement of Required Fidelity Level

Not specified.

C. Variables Affecting Required Fidelity Level

Amount of transfer of skill from simulator to the operational system, visual input, control and kinesthetic feedback, motion input, environmental factors.

D. Criteria for Determining Required Fidelity Level

Not specifically stated.

E. Methods for Determining Required Fidelity Level

Quantitative assessment of fidelity and resulting learning transfer effects, pilot ratings, pilot transfer functions, physiologic measurement comparisons, proficiency measurements.

IV. SIMULATORS IN TRAINING SYSTEMS

A. Relationship to Training for Specified Tasks

Part-task simulators can be just as effective as more comprehensive devices for specific tasks.

B. Relationship to Training Effectiveness

Flight simulators generally very useful but amount of skill transfer from simulator to aircraft depends on a variety of factors still subject to experimental research.

C. Methods for Establishing Training Effectiveness

Pilot ratings; mathematical expressions of input-output relationship of the human operator in the control system; comparison of physiologic responses: simulator/real system; performance comparison: simulator/real system.

D. Simulators as Part of Training Systems

Not addressed.

Grimsley, D. L. Acquisition, Retention and Retraining: Group Studies on Using Low Fidelity Training Devices. Report No. HumRRO-TR-69-4. Alexandria, VA: Human Resources Research Office, 1969. (NTIS No. AD-686 741)

I. GENERAL SUMMARY

A. Focal Industry

U.S. Army.

B. Type of Document

Technical report; primary research.

C. Basic Objective(s)

This is a report of a series of experiments, the purpose of which was (a) to examine the effects of varying fidelity of training devices on acquisition, retention and reinstatement of performance of a procedural task when group training procedures were used, and (b) to obtain additional information on the effectiveness of low fidelity devices for training and retraining.

D. Major Findings or Recommendations

Five different studies were performed. While experimental conditions varied, in general each of the 120 subjects was tested after training, on his ability to perform the 92-step procedural task; subjects were again tested four and six weeks later to see how much of the procedure was remembered; after the final test they were trained to criterion.

The results indicated that there were no significant differences in training time, initial performance level, amount remembered after four and six weeks, or retraining time between groups trained on high and those trained on low fidelity devices. These findings are in complete agreement with earlier reported results indicating that no difference exists, whether training is individually or group administered.

The fidelity of training devices used to train men to perform procedural tasks can be very low with no adverse effect on training time, level of proficiency, retention or time to retrain. This is true whether the training is individually or group administered. Brief practice on the high fidelity device facilitates the performance of groups trained on the low fidelity device. The low fidelity device in conjunction with a list of the correct actions, can be used to effectively reinstate a high level of performance after a passage of time, regardless of the device used for original training. A careful review of tasks to be taught should precede selection of training devices. Low fidelity devices may be used to considerable advantage both for economy in training and for effectiveness of training, remembering and retraining.

II. SIMULATOR TOPIC FOCUS

A. Uses of Simulator Addressed

Training, retraining.

B. Types of Simulator Addressed

Low fidelity simulator, high fidelity simulator.

III. SIMULATOR FIDELITY

A. Fidelity Dimensions and Definitions

Devices used for testing differed in their level of functional or appearance fidelity. Fidelity is defined to be the degree to which a device resembles the tactical equipment for which it is a substitute.

B. Explicit Statement of Required Fidelity Level

Three levels of fidelity specified: (1) hot panel = physical duplicate of the tactical equipment; (2) cold panel = identical to hot panel except for none of the instrumentation worked; and (3) reproduced panel = artist's representation of the hot panel.

C. Variables Affecting Required Fidelity Level

Training time, initial performance level, amount remembered after four and six weeks, retraining time.

D. Criteria for Determining Required Fidelity Level

Presumably results of previous series of experiments.

E. Methods for Determining Required Fidelity Level

Previous series of experiments.

IV. SIMULATORS IN TRAINING SYSTEMS

A. Relationship to Training for Specified Tasks

People can effectively be trained to perform a procedural task as well on a very simple, low fidelity reproduction as on a functional, high-fidelity device. For fixed procedural tasks, fidelity of the training device is relatively unimportant. It has been shown that low-fidelity devices are as good as the real equipment for training the following tasks: (1) learning basic instrument and rapid-range procedures in aircraft; (2) control of course and depth of a submarine; (3) pre-start check, engine-start, engine-run up and engine shut-down of an aircraft; (4) preparation and firing status of a Nike-Hercules guided missile system; and (5) starting and stopping procedures in a tank.

B. Relationship to Training Effectiveness

The implication is not that low fidelity trainers may substitute for complex trainers, but rather that, for procedural tasks and for early stages of certain types of training, devices other than procedural, low fidelity, trainers are uneconomical and unnecessary.

C. Methods for Establishing Training Effectiveness

Instructor present during testing scored trainee's errors. Each step omitted or taken out of sequence constituted an error. Any question about procedure asked by the trainees was answered by the instructor and an error scored for that step. Criterion score was 92, one point for each correct step in the procedure.

D. Simulators as Part of Training System

Simulation training only part of overall training program. Training device use has to be integrated into complete program.

Hammell, T. J., Williams, K. E., Grasso, J. A., & Evans, W. Simulators for Mariner Training and Licensing Phase 1: Role of Simulators in the Mariner Training and Licensing Process. Volume 1. Report No. CAORF-50-7810-01-Vol 1. Kings Point, NY: National Maritime Research Center, 1980. (NTIS No. AD-A091 926)

I. GENERAL SUMMARY OF THE DOCUMENT

A. Focal Industry

Civil maritime industry.

B. Type of Document

Literature review; description of ongoing research.

C. Basic Objective(s)

The document is a literature review on the use of simulators generally and also reports on a multiphase research project carried out by the Department of Commerce on integration of simulator use into master mariner training programs.

D. Major Findings or Recommendations

The report gives full and explicit account of the systematic development of training objectives and training program development. Maritime operations are seen as different from those in the aviation and nuclear power areas: maritime operations require more independent decision-making and less dependence on complex sequential procedural tasks. The value of simulation training is unclear for decison-making training.

The research showed that a systems approach to training is applicable to the investigation of simulation in mariner training and licensing. The recommended methodology emphasizes identification of specific functional objectives. Training has capabilities and limitations which should be considered when deciding its use. Elements of a training system, including simulation, should be designed on the basis of objective cost-effectiveness information.

On the basis of safety, cost, and training control, the simulator appears preferable to on-the-job training for most skills, especially those skills related to emergency situations.

Considerable research is needed to determine the relative training effects of different types of simulators with regards to the identified specific functional training objectives. A modular structure to the training program is recommended, coupled with diagnostic evaluation and individual program tailoring, to meet the needs of trainees with divergent skills and knowledge.

II. SIMULATOR TOPIC FOCUS

A. Uses of Simulators Addressed

Training, licensing, team-training.

B. Types of Simulators Addressed

Full-task and part-task.

III. SIMULATOR FIDELITY

A. Fidelity Dimensions and Definitions

No explicit ones made.

B. Explicit Statement of Required Fidelity Level

Some quantitative assessments are made for visual and audio simulation subsystems. General statements include that for team training high fidelity is essential for positive training transfer independent of the degree of team interaction required.

C. Variables Affecting Required Fidelity Level

No objective experimental data exist for defining impact of fidelity level on assimilation and evaluation of information and resultant decision-making process of trainees.

D. Criteria for Determining Required Fidelity Level

Characteristic alternative effectiveness ratings which are scales of effectiveness values (0-5) that assess relative capabilities of alternative simulator characteristics to improve and demonstrate skills contained in the specific functional objectives.

E. Methods for Determining Required Fidelity Level

See III-B.

IV. SIMULATORS IN TRAINING SYSTEMS

A. Relationship to Training for Specified Tasks

Simulator program needs to be responsive to individual needs where trainees have widely differing proficiencies and expertise. Training can be pure part-task, progressive part-task, simplified whole-task, or whole-task in general; progressive part-task training could be the primary method for complex, highly unorganized tasks; whole-task training should be primary method in all other cases.

B. Relationship to Training Effectiveness

Direct relationship not shown due to lack of research. Variation in training tasks seems to be key factor in training for positive transfer. Feedback to the trainee is very important.

C. Methods for Establishing Training Effectiveness

Definition of performance measures tied to specific functional training objectives. Pre- and post-training exercises. Transfer of training is demonstration of improvement of on-the-job performance as a function of the simulator training program. The transfer effectiveness ratio gives the operational training hours saved per hour of simulator use to reach a given proficiency of operator performance. The ratio is defined as:

$$\frac{\text{Control Group Hours (Non-simulator) - Experimental Group Hours (Simulator)}}{\text{Simulator Hours Used by Experimental Group}}$$

Criteria for training effectiveness are: validity, efficiency and practicality.

D. Simulators as Part of Training Systems

Design of simulator training program needs to be closely integrated with other training elements. Other elements can have equal or greater effectiveness than simulators depending on the training task. Appendix E contains tables of appropriate training system elements for specific functional objectives defined by this report.

Training should be in areas of weak skills only. Weaknesses to be defined by tests on skill modules established by systematic instructional development.

Hammerton, M. Factors affecting the use of simulators for training. Proceedings of the IEE, 1966, 113(11), 1881-1884.

I. GENERAL SUMMARY

A. Focal Industry

General.

B. Type of Document

Research findings presented at professional meeting.

C. Basic Objective(s)

The paper reviews and discusses the implications of a series of experiments germane to the use of simulators for training purposes.

D. Major Findings or Recommendations

Problems of measuring transfer of training are briefly discussed and a series of nine experiments is summarized. Each experiment is concerned with visual or environmental factors which can affect the usefulness of a training simulator. It is quite clear, from the results obtained, that for really good transfer of training more is needed than precise simulation of the control dynamics and display kinematics of the real situation. It seems that minor differences of environment between the training and real situations can be tolerated. It is important to note that considerble savings of training time can be obtained with relatively simple displays and that it is only necessary to pay for more elaborate ones if immediate transfer of performance is an important requirement. This must be decided in each individual case by thorough cost-accounting and examination of accident risks. Also, in order to obtain a useful measure of the efficiency of a simulator, it is necessary to be very clear about what it is needed for and to select the relevant measuring parameter.

II. SIMULATOR TOPIC FOCUS

A. Uses of Simulator Addressed

Training, research.

B. Type of Simulator Addressed

Part-task, dynamic.

III. SIMULATOR FIDELITY

A. Dimensions and Definitions

Variations of visual stimulation fidelity.

B. Explicit Statement of Required Fidelity Needed

Object of experiments was to see how changes in visual fidelity affected transfer of performance training. One major conclusion was that both adequate background detail and adequate depth cues must be provided by the simulator display (the experiments involved control of a moving object as viewed through television or cathode ray tube displays).

C. Variables Affecting Need for Required Fidelity

Accurate reproduction of control dynamics and display kinematics to be found in the real situation.

D. Criteria for Determining Required Fidelity Level

Experiment specific.

E. Method For Determining Needed Fidelity Level

Comparison of performance by experimental and control group members.

IV. SIMULATORS IN TRAINING SYSTEMS

A. Relationship to Training for Specified Tasks

Experimental task very specified but no general observations made on the relationship.

B. Relationship to Training Effectiveness

Study used three measures.

1. What is the saving of training trials in the real situation?

Answer given by: $\alpha = \frac{n - r}{n}$

n = number of trials needed by control group to reach a stable performance

r = number of post simulator transfer trials needed by the experimental group to do the same

2. Given a certain amount of learning with the simulator, how much of it will be retained on first transferring to the real situation?

   Answer given by: $\beta = \frac{F - T}{F = L}$

   F = mean performance on the first simulator training trial

   L = mean performance on the last simulator training trial

   T = mean performance on the first post-transfer trial

3. How does the training retained on the first post-transfer trial compare with that gained by trainees who always used the real thing?

   Answer given by: $\gamma = \frac{C - T}{C - S}$

   C = mean first-trial performance of the control group

   S = stable (trained) control group performance

   T = mean performance on the first post-transfer trial by the experimental group.

For each of the nine reported experiments, α, β, and γ values were calculated, compared and discussed.

C. Methods for Establishing Training Effectiveness of Simulators:

See IV-B.

D. Simulators as Part of Training System

To obtain a useful measure of the efficiency of a simulator it is necessary to be very clear about what it is needed for--the saving of training time or the initial performance of trainees immediately after training.

Herrick, R. M., Wright, J. B., & Bromberger, R. A. Simulators in Aviation Maintenance Training: A Delphi Study. Report No. NADC-78015-60. Warminster, PA: Naval Air Development Center, 1977. (NTIS No. AD-A052 715)

I. GENERAL SUMMARY OF THE DOCUMENT

A. Focal Industry

U.S. Naval Air Arm.

B. Type of Document

Technical report; primary research.

C. Basic Objective(s)

The study gathered expert opinion on the use of simulators for training aviation maintenance technicians.

D. Major Findings or Recommendations

Following the Delphi technique, three successive questionnaires were administred to 60 experts. The questionnaires asked what information an administrator needed to decide between simulators and real equipment for training. Included under information requirements were: areas of course content, economics, life-cycles, repairs, students and instructors. Suggested sources of information were considered. Additionally, the experts rated the feasibility, training effectiveness, and cost effectiveness of simulators for maintenance training for nine aircraft systems. The questionnaire data were analyzed separately for military maintenance instructors versus all other experts. Although both groups agreed with each other in most areas, a few differences that may have significant practical applications were uncovered. The instructor group disagreed among themselves concerning the feasibility, training effectiveness and cost effectiveness of simulation for I-Level maintenance training while the other experts were often in agreement and generally in favor of simulation for I-Level training.

I-Level = Intermediate Level Aircraft Maintenance Training

O-Level = Organizational Level Aircraft Maintenance Training

II. SIMULATOR TOPIC FOCUS

A. Uses of Simulators Addressed

Aircraft equipment maintenance training.

B. Types of Simulators Addressed

Limited to simulators costing less than $200,000 (1977); non-specific as to type of simulator.

III. SIMULATOR FIDELITY

A. Fidelity Dimensions and Definitions

Not addressed.

B. Explicit Statement of Required Fidelity Level

Not addressed.

C. Variables Affecting Required Fidelity Level

Not addressed.

D. Criteria for Determining Required Fidelity Level

Not addressed.

E. Methods for Determining Required Fidelity Level

Not addressed.

IV. SIMULATORS IN TRAINING SYSTEMS

A. Relationship to Training for Specified Tasks

Simulators are more effective than operational equipment for organizational level maintenance training. In general for intermediate level training the maintenance instructor experts held a rather dim view of simulation for this level of training while the remaining experts felt, at least for some systems, that simulation was both feasible and cost effective.

B. Relationship to Training Effectiveness

General agreement that simulators are effective, some disagreement as to appropriate level for which they should be used rather than operational equipment.

C. Methods for Establishing Training Effectiveness

Not addressed.

D. Simulators as Part of Training Systems

Need for integration into systematically developed training program.

Hughes, T. E. C., & O'Halloran, J. T. The use of simulation in the training of nuclear power plant operators. Proceedings of NTEC/Industry Conference (7th) November 19-21, 1974. Report No. NAVTRAEQUIPCEN-IH-240. Orlando, FL: Naval Training Equipment Center, 1974. (NTIS No. AD-A000 970/4SL)

I. GENERAL SUMMARY

A. Focal Industry

Nuclear power industry.

B. Type of Document

The paper is a review of the literature on the use of simulators for plant operators.

C. Basic Objective(s)

Training in normal operating procedures and in procedures to cope with emergencies is required. Simulators have been built so that operator actions possible in real control rooms are also possible in the simulated control room. As nuclear power plants become more complex, operations become more demanding, operations costs increase and demand for available trained manpower increases, utilities will require more simulators to provide operational training for large-scale plants. The large financial investment that is a nuclear power plant is the responsibility of the three to five operators and support personnel who must weigh their decisions against administrative and regulatory standards to assure safe and efficient plant operation.

D. Major Findings or Recommendations

The article considers the issue of setting national standards for simulation use in training and requalification.

II. SIMULATOR TOPIC FOCUS

A. Uses of Simulator Addressed

Training, requalification.

B. Types of Simulator Addressed

Full-scale, high fidelity.

III. SIMULATOR FIDELITY

A. Dimensions and Definitions

Not addressed.

B. Explicit Statement on Fidelity Level Required

Not given.

C. Variables Affecting Need for Required Fidelity

Continuous, real-time representation of physical characteristics of the simulated plant, accurate representation of physical and functional characteristics, component performance, layout and instrumentation of the control room, development of mathematical models to represent plant systems.

D. Criteria for Determining Required Fidelity Level

Clearly define training requirements to be met by simulator. State simulation tolerances, both for system performance and system interdependency, necesary to meet training requirements, specify the fidelity and scope of simulation of normal, emergency and abnormal operating conditions required for training and requalification programs.

E. Methods for Determining Fidelity Level Needed

Not addressed.

IV. SIMULATORS IN TRAINING SYSTEMS

A. Relationships to Specified Tasks

Requalification experience specified by NRC (AEC)--practice of reactivity control manipulations, evaluation of operator response to abnormal and emergency conditions.

B. Relationship to Training Effectiveness

Simulators help in improving decision making by developing judgment. Simulators have a definite advantage in the area of systematic presentation of repetitive experiences. Improvements in decision making come from repetition. Realism is important. To handle emergency and abnormal events, information must be realistic and the acceptable decisions must be the same ones which must be made on the job. A good nuclear power plant simulator must provide information feedback to tell that person whether or not they were successful.

C. Methods for Establishing Training Effectiveness

Not addressed.

D. Simulators as Part of Training System

Need criteria and guidelines for simulator manufacturers and utilities for use of simulators in training and requalification.

Johnson, S. L. Training devices: Physical versus psychological simulation. Human Factors in Our Expanding Technology: Proceedings of the Human Factors Society 19th Annual Meeting. Santa Monica, CA: Human Factors Society, 1975.

I. GENERAL SUMMARY OF THE DOCUMENT

A. Focal Industry

No industry discussed.

B. Type of Document

Descriptive article.

C. Basic Objective(s)

The paper is one of a series of articles that examine current (1975) knowledge about definition of requirements for training devices. The article contrasts physical and psychological simulation, and describes a theoretical approach to determining the level of physical cue fidelity necessary to give adequate psychological simulation.

D. Major Findings or Recommendations

Training specialists still do not know what is necessary in a simulator to give effective training. The behavioral variables in simulation fall into three broad categories: simulation fidelity; external influences on level of fidelity needed (e.g., experience of trainees); measure of training effectiveness. The goal of training in simulators is to teach behavior that falls within an acceptable range when transferred to the operational system. It is useful to discuss this requirement in terms of stimuli presented to the trainee and responses made by the trainee. Human processing of physical stimuli is complex, involving sensory and perceptual systems. In these systems, there are "thresholds" for detection of stimuli ("absolute thresholds") and for detection of changes in stimuli ("difference thresholds"). These thresholds can be significantly changed by changes in variables such as stress, fatigue and task loading; they are also affected by individuals' personal criteria for stating that a signal was detected. The workings of human sensory and perceptual systems should be taken into account in setting requirements for fidelity of simulators. When this is done, the result is "psychological simulation" rather than "physical simulation" (which focuses on physical equipment similarity alone).

Two key issues in psychological simulation are discrimination training and generalization training. In discrimination training, the trainee learns to reliably tell the difference between two cues or sets of cues. (Cues are defined as "stimulus information to the operator that informs him to initiate an action or to complete an action.") Discrimination is important when different responses are necessary for different cues, and when criticality and/or frequency of the cue situation are high. The simulator designer should determine both the minimum number of cues needed to make the correct response, and the minimum fidelity of individual cues needed to permit discrimination.

The problem in generalization training is to assure that the trainee will give the correct response to cues that differ somewhat from those used in training, but still belong to the same class of cues. Success depends on inclusion of a large enough range of values of the cues in the simulator.

Discrimination and generalization curves should be generated for the many different tasks that are to be trained.

II. SIMULATOR TOPIC FOCUS

A. Uses of Simulators Addressed

Training.

B. Types of Simulators Addressed

Not specified; full-scale and part-task implied.

III. SIMULATOR FIDELITY

A. Fidelity Dimensions and Definitions

Dimensions: physical, psychological.

Definitions of fidelity are not given, but definitions of simulation apply. Physical simulation: "reproduce the real world" to the greatest extent possible.

Psychological simulation: (1) "Intentional deviation from 'reality' can be cost-effective and even increase the training potential of a device"; (2) ". . . problem of transfer of training from the device to the aircraft tasks."

B. Explicit Statement of Required Fidelity Level

Not addressed.

C. Variables Affecting Required Fidelity Level

Discriminability of cues and importance of discriminability; experience level of trainees; tasks to be performed by trainees after training.

D. Criteria for Determining Required Fidelity Level

"When the same response is elicited from a low fidelity cue as from a high fidelity cue, then the cost of high fidelilty is not justified. However, if different responses are required to two different cues, then negative transfer will occur if the cues are 'functionally identical' (i.e., not discriminable). In this case, for positive transfer, the fidelity of the simulation must be adequate to insure that the trainee can discriminate among the cues. The task of the training device designer, therefore, is to establish the minimum fidelity of the cues that will ensure the discrimination."

E. Methods for Determining Required Fidelity Level

Not addressed.

IV. SIMULATORS IN TRAINING SYSTEMS

A. Relationship to Training for Specified Tasks

Not addressed.

B. Relationship to Training Effectiveness

Not addressed.

C. Methods for Establishing Training Effectiveness

Not addressed.

D. Simulators as Part of Training Systems

Not addressed.

Johnson, S. L. Effect of training device on retention and transfer of a procedural task. Human Factors, 1981, 23(3), 257-272.

I. GENERAL SUMMARY OF THE DOCUMENT

A. Focal Industry

Manufacturing industry.

B. Type of Document

Journal article; report of primary research.

C. Basic Objective(s)

The research investigated the effectiveness of three different training devices, varying in fidelity, with respect to initial training, training retention, and transfer of training.

D. Major Findings or Recommendations

The training devices were designed to require varying degrees of visual imagery utilization in learning a sequential procedural task. The particular task used was representative of many sequential procedures in aircraft. The results of the study indicate that (1) training devices do not need to be of high fidelity to be effective for the training of procedure-following tasks; (2) the consideration of how the human operator processes and stores information, rather than a concentration on the properties of the incoming information, can improve the effectiveness of training. The use of a training strategy that requires the trainees to provide their own cueing and feedback from memory is effective in increasing the retention of procedure-following skills over a prolonged period of time. The increased retention, without associated disadvantages during initial training, is particularly important when the cost-benefits of using lower fidelity devices are considered. Besides the implications for dollar cost, the results also have important implications for initial and refresher training as well as for the retention efficiency of an important type of current work activity, procedural tasks.

II. SIMULATOR TOPIC FOCUS

A. Uses of Simulators Addressed

Training, retraining.

B. Types of Simulators Addressed

Whole-task simulator.

III. SIMULATOR FIDELITY

A. Fidelity Dimensions and Definitions

Fidelity is a close synonym of realism.

B. Explicit Statement of Required Fidelity Level

Not given.

C. Variables Affecting Required Fidelity Level

There are two primary categories of information relating to fidelity of procedural training devices. First is cueing of the trainee. That is, if the trainee cannot remember the exact setting at which a gauge should be set, the range and graduations on the display gauge can cue or prompt the correct response. In the same sense, seeing the resultant effect of one action can cue the trainee as to the next action in a sequence. The second category of information involves feedback to the trainee as to the result (and possibly the correctness) of the action. Although in some situations these two categories are difficult to separate (e.g., a signal can be both beedback from the previous action as well as a cue to the next), they have different implications for a training device. The cueing characteristic often requires an active console--programmer or instructor operated, whereas the feedback characteristics often require an active and interactive capability--the equipment must respond differently depending upon the trainee's inputs.

D. Criteria for Determining Required Fidelity Level

The meaningfulness or realism of the training task undoubtedly influences the motivation of the trainee and it also imparts an inherent organization to the task that could be important for retention. Other criteria include the effect of the training device on the ability to retain a procedure-following skill over an interval of time without practice and the ability of the trainee to transfer from one procedure to a similar but different procedure as a function of the training device used.

E. Methods for Determining Required Fidelity Level

The effect of training device fidelity on training effectiveness was investigated by using three different devices, each of which required different degrees of visual imagery. The requirement for visual imagery memory was manipulated by varying the stimuli that provided the trainee with visual cueing and feedback. Subjects were randomly assigned to the three devices. The analysis statistically compared the performance measures for each device group. The results of the study support the idea that the fidelity of a training device does not necessarily make an impact on the number of trials an individual must perform to learn a task.

IV. SIMULATORS IN TRAINING SYSTEMS

A. Relationship to Training for Specified Tasks

Research suggests that simulators can be effective in training procedural tasks.

B. Relationship to Training Effectiveness

The study results agree with the conclusion that a training device does not have to involve high fidelity to facilitate positive transfer of training. The results also show that an operator can learn a task involving close to 100 steps, without use of a checklist, in less than ten repetitions of the task sequence as long as there is a coherent set of associations within the task sequence. The consideration of how the human operator processes and stores information, rather than a concentration on the physical properties of the incoming information, can improve the effectiveness of training. The use of a training device that requires the trainee to provide cueing and feedback from memory is effective in increasing the retention of procedure-following skills over a prolonged period of time.

C. Methods for Establishing Training Effectiveness

Use of training criteria--training time or terminal proficiency level--terminal proficiency chosen. Experimental paradigm for measuring training effectiveness included: initial training, retention evaluation tests, retraining and task transfer of training.

D. Simulators as Part of Training Systems

Training effectiveness of a simulator is a function of the manner the device is used within a planned training program.

Maslo, R. M. Advanced simulator incorporates design as well as training capability. Power Engineering, 1980, 84(10), 77-81.

I. GENERAL SUMMARY OF THE DOCUMENT

A. Focal Industry

The nuclear power industry is the focus of this article and it deals explicitly with the use of simulators for training, design, and procedure development.

B. Type of Document

Position paper.

C. Basic Objective(s)

The article is a position paper on the use of parallel-hybrid simulators and also reviews the present capabilities of training simulators.

D. Major Findings or Recommendations

Better-trained operators can be attributed to the utilities' use of training simulators. Simulator training success rests on technological advances in computer hardware and software. Realism is the most important aspect of the trainee's simulator curriculum. Exact duplication of plant dynamics is coupled with improved instructor aids such as back track, replay, control board and panel override, and interactive processors.

Utilities have been able to study plant modifications on the simulators. If the fidelity of the mathematical models of plant behavior is sufficient, the simulators would be useful for analyzing current plant status and predicting future plant dynamics. The proposed parallel-hybrid simulator allows the insertion of complex engineering plant models into the simulator together with simplified training models. With parallel-hybrid simulators, design engineers can study subsystem dynamics under stress while trainees are running the simulator through various transient conditions. The simulator is seen as two systems: a training simulator and an engineering simulator capable of joint or independent operation. The capability for accurate, physical dynamic simulation is greater in the engineering than the training simulator. The article presents an example of a detailed engineering model of a pressurizer system.

II. SIMULATOR TOPIC FOCUS

A. Uses of Simulators Addressed

Training, retraining, plant design, procedures development, predictive use during transients.

B. Types of Simulators Addressed

High-fidelity, full-scale, dynamic simulators driven by digital and analogue computers (Digital + Analogue = Hybrid).

III. SIMULATOR FIDELITY

A. Fidelity Dimensions and Definitions

Not addressed.

B. Explicit Statement of Required Fidelity Level

Maximum realism, physical replication possible.

C. Variables Affecting Required Fidelity Level

Real time response capability, accuracy of mathematical modeling for duplicating plant or subsystem response.

D. Criteria for Determining Required Fidelity Level

Not stated.

E. Methods for Determining Required Fidelity Level

Not addressed.

IV. SIMULATORS IN TRAINING SYSTEMS

A. Relationship to Training for Specified Tasks

Not addressed.

B. Relationship to Training Effectiveness

Not addressed.

C. Methods for Establishing Training Effectiveness

Not addressed.

D. Simulators as Part of Training Systems

Not addressed.

McCluskey, M. R. Perspectives on Simulation and Miniaturization, Report No. HumRRO-PP-14-72. Alexandria, VA: Human Resources Research Organization, 1972. (NTIS No. AD-748 082)

I. GENERAL SUMMARY OF DOCUMENT

A. Focal Industry

Military.

B. Type of Document

Research review and conceptual framework development.

C. Basic Objective(s)

This short paper attempts to provide a conceptual framework for making decisions regarding the use of simulators. Training applications of simulation (and miniaturization) are examined, as are areas where research is needed to develop cost-effective simulation methdologies for training.

D. Major Findings or Recommendations

For simulation to be effective, systems analysis is needed to define physical and psychological dimensions, relationships and aspects, such as: equipment components, personnel, organization, system procedures and processes, input and output data and system environment. When the following questions are answered, simulation techniques should develop as some of the most cost-effective means of training:

1. What task and equipment aspects require high fidelity representation?

2. What are the most cost-effective levels of fidelity?

3. What is the most effective combination of simulated and real-world experience?

4. What relationships exist between psychological fidelity and simulation factors?

5. What perceptual cues require high fidelity representation?

6. What relationships exist among perceptual cues and task demands?

When using simulation techniques, the intention is that observations and findings will transfer and apply to the real-world system. Thus, defining the conditions of transfer becomes the most important phase in the use of simulation techniques. The degree of transfer appears to be directly related to fidelity. Studies have indicated that psychological fidelity is more important for adequate transfer than physical fidelity. Although it is probably true that high fidelity simulation is a necessary condition for transfer, it is a matter of which dimensions and attributes to be selected and how accurately they should be represented to obtain cost-effective transfer.

In the absence of information, there is a tendency to request high physical fidelity as a precaution. In the majority of systems this is a fairly expensive safeguard of unknown value. The expenditure of funds to achieve high fidelity simulation probably far exceeds the cost for systems analysis and research to determine the levels of physical and psychological fidelity required for equal or better transfer. It must be ensured that high physical fidelity is an actual requirement related to the psychological dimensions of performance. If high fidelity is included unnecessarily, it becomes very difficult to achieve cost-effective transfer. The compromises made between physical and psychological fidelity, cost and training transfer require constant and thorough evaluation.

II. SIMULATOR TOPIC FOCUS

A. Uses of Simulators Addressed

Training, performance measurement, system evaluation and system research.

B. Types of Simulators Addressed

Replication, laboratory, computer and analytical simulation and miniaturization.

III. SIMULATOR FIDELITY

A. Fidelity Dimensions and Definitions

The fidelity of simulation is composed of both physical and psychological dimensions. Physical fidelity is the extent to which the simulation represents the environment and operational equipment of the real system. Psychological fidelity is the degree of similarity that can be created between the psychological demands of the simulated and real-world tasks.

Dimensions to psychological fidelity include: reactions to the scope, extent or segment of the environment represented in the simulation; the duration of the interaction between man and environment; the degree of mediacy between the person and the environment, in terms of both perceptual and effective interactions; the importance and degree of involvement with interpersonal relationships; the extent of perceived realism and related cognitive states.

B. Explicit Statement of Required Fidelity Level

Not made.

C. Variables Affecting Required Fidelity Level

See III-A.

D. Criteria for Determining Required Fidelity Level

Not given.

E. Methods for Determining Required Fidelity Level

Not addressed.

IV. SIMULATORS IN TRAINING SYSTEMS

A. Relationship to Training for Specified Tasks

Systems analysis results in performance requirements and conditions of performance to determine where simulation will be most effective.

B. Relationship to Training Effectiveness

Observation made that psychological fidelity most probably more important for training effectiveness than physical fidelity.

C. Methods for Establishing Training Effectiveness

Experiments using experimental and control groups.

D. Simulators as Part of Training Systems

Before simulation techniques can be effective, considerable research is needed to define the conditions of training transfer to the real world. A complete systems analysis is required to define the physical and psychological dimensions and relationships. Definition of user need; definition of system performance requirements; determination of simulation cost-effectiveness; selection of system elements for simulation; construction of simulator to maximize transfer; specification of simulation outputs; verification of training transfer.

Micheli, G S. Analysis of the Transfer of Training, Substitution, and Fidelity of Simulation of Training Equipment. TAEG Report 2. Orlando, FL: Naval Training Equipment Center, 1972. (NTIS No. AD-748 594)

I. GENERAL SUMMARY OF THE DOCUMENT

A. Focal Industry

Military.

B. Type of Document

Technical report; research reviews.

C. Basic Objective(s)

The report summarizes, evaluates, and synthesizes the data on the training value of training devices

D. Major Findings or Recommendations

The report discusses the issue of substitution of some operational training time by training devices and the relationship between training effectiveness and cost. The report found that generally, despite differing degrees of fidelity, there was no difference in transfer effect between trainers. It is contended that training effectiveness is more a function of how the trainer is used than of the fidelity of the trainer. The goal of approaching complete duplication of operational equipment should not be attempted unless a training situation analysis reveals its necessity. Training effectiveness evaluations of training systems have demonstrated that learning, retention and transfer occur in situations where "exact simulation" is not present. Training effectiveness results not from attempting to approach identity of task elements, but from using a training device in a manner that permits trainees to practice the behaviors critical for performance in the operational situation.

II. SIMULATOR TOPIC FOCUS

A. Uses of Simulators Addressed

Training.

B. Types of Simulators Addressed

Full-scale and part-task.

III. SIMULATOR FIDELITY

A. Fidelity Dimensions and Definitions

Not addressed.

B. Explicit Statement of Required Fidelity Level

Not made.

C. Variables Affecting Required Fidelity Level

Type of task, mode of use of simulator, training effectiveness.

D. Criteria for Determining Required Fidelity Level

Training effectiveness, cost.

E. Methods for Determining Required Fidelity Level

Transfer-of-training experiments with experimental and control groups.

IV. SIMULATORS IN TRAINING SYSTEMS

A. Relationship to Training for Specified Tasks

Simulators have cost and training value for pilot training. Substantial amounts of simulator time can be used in place of flight time. Different kinds of flight tasks have different transfer effects. Simulators are best for procedural and instrument flying tasks. Complex maneuvers have not been learned well with past state-of-the-art simulators (1972).

B. Relationship to Training Effectiveness

$$\% \text{ Transfer Effect} = \frac{Z_c - Z_e}{Z_c} \times 100$$

Z_c = Performance or time required on the operational or simulated task by the control group

Z_e = Corresponding value for the experimental group.

$$\text{Transfer Effectiveness Ratio} = \frac{Y_c - Y_e}{X_e}$$

Y_c = Time required by control group to reach some criterion of proficiency in the operational or simulated task.

Y_e = Corresponding value for the experimental group.

X_e = Amount of simulator use time by experimental group.

The same simulator may exhibit different transfer effectiveness ratios depending on the criterion of performance used. Also, for different stages of a curriculum, a simulator may have different ratio values. The ratio value will also depend on how the simulator is used.

C. Methods for Establishing Training Effectiveness

Flight check scores, performance measurement.

D. Simulators as Part of Training Systems

How simulator used is more important for training effectiveness than the design or fidelity of the simulator.

Miller, R. L. Techniques for the Initial Evaluation of Flight Simulator Effectiveness. Wright-Patterson Air Force Base, OH: Air Force Institute of Techology, December 1976. (NTIS No. AD-A036 460/4ST)

I. GENERAL SUMMARY OF THE DOCUMENT

A. Focal Industry

Military flight.

B. Type of Document

Master's thesis report of literature review and research project.

C. Basic Objective(s)

The document provides an analysis of the development and initial (i.e. prior to delivery) evaluation of Air Force flight simulators that are used for aircrew training. The purpose of the study was to identify criterion variables most appropriate for initial flight simulator evaluation and to devise general techniques of evaluating criterion variables.

D. Major Findings or Recommendations

Complete evaluation of a flight simulator would include estimates of military utility, operational effectiveness, compatibility, interoperability, reliability, maintainability, logistic supportability, cost of ownership, and training requirements. This research focused on operational effectiveness ("how well the system performs its intended mission when operated in its intended environment"). Evaluation of simulator training effectiveness has become increasingly important and increasingly difficult, as technology and cost have advanced. The author reports on research that addresses the problem.

Current Navy, Army and Air Force flight simulator development and evaluation techniques were reviewed. It was found that the purpose of most of these evaluation techniques is to determine the fidelity or accuracy of simulation. On the basis of the review, the researcher selected criterion variables for further study. These included: aircraft flight time saved, training effectiveness, transfer of training, fidelity of psychological simulation, fidelity of engineering simulation, and simulator effectiveness. The criterion variables were studied to determine their measurablility during initial flight simulator evaluation and their ability to predict performance of flight simulators. The researcher concluded that simulator effectiveness (equivalent to operational effectiveness) was the preferred criterion variable for initial flight simulator evaluation. The following relationships were proposed: Simulator Effectiveness = Aircraft Flight Time Saved + Quality of Training = Training Efficiency + Transfer of Training = Fidelity of Psychological Simulation = f(Fidelity of Engineering Simulation).

A technique for evaluation of applicable criterion variables was developed. The technique combines traditional quantitative techniques with some subjective techniques. The purpose of the quantitative methods is to develop the simulator to an initial minimum acceptable level of physical fidelity. This process entails generation of a mathematical model representing characteristics of flight in the aircraft being simulated, to be converted into a real-time mathematical model for the flight simulator computer.

The subjective evaluation techniques are employed to determine those aspects of physical fidelity whose improvement would yield the greatest improvements in simulator effectiveness. Only pilots qualified as instructors in the aircraft being simulated, are capable of giving adequate subjective evaluations.

II. SIMULATOR TOPIC FOCUS

A. Uses of Simulators Addressed

Aircrew training; evaluation of engineering and human factors mentioned.

B. Types of Simulators Addressed

Procedural trainers; flight simulators: full-scale, part-task, dynamic.

III. SIMULATOR FIDELITY

A. Fidelity Dimensions and Definitions

Physical (engineering simulation); psychological.

Fidelity of engineering simulation: "A measurement of how well the physical characteristics of the real world aircraft have been copied in the flight simulator."

Fidelity of psychological simulation: "A measurement of how the thought processes generated by training in the flight simulator affect the thought processes required for performance in the aircraft . . . includes the concepts of training effectiveness and transfer of training. It is also equivalent to flight simulator effectiveness."

B. Explicit Statement of Required Fidelity Level

"It is not possible to establish a level of fidelity of engineering simulation that would be the most cost effective for any given task."

C. Variables Affecting Required Fidelity Level

See III-D below

D. Criteria for Determining Required Fidelity Level

Simulator effectiveness and cost (a suggested general relationship was depicted graphically).

E. Methods for Determining Required Fidelity Level

Initially develop flight simulator to lower level of fidelity of engineering simulation. Make estimates of simulator effectiveness. Increase fidelity of those aspects that have not reached the point of diminishing returns (as determined by a judgment regarding the tradeoff between increased cost and training effectiveness).

IV SIMULATORS IN TRAINING SYSTEMS

A. Relationship to Training for Specified Tasks

Not addressed.

B. Relationship to Training Effectiveness

"The quality of training in a flight simulator is a composite of the efficiency of original learning, the transfer of what was learned in the simulator to performance in the aircraft, and the retention of what was learned. . . . Each of these elements of training are dependent on many variables, only a few of which are related to the characteristics of the flight simulator. Very little is known about which variables have the most important impact on quality of training."

C. Methods for Establishing Training Effectiveness

Generally: identify flight simulator properties and then discover the relationship between each property and training effectiveness of simulator. The first step is to determine which flight simulator properties to use as criterion variables for evaluation. The second step is to select techniques of measuring those properties.

D. Simulators as Part of Training Systems

"Good training programs are the result of a substantial amount of experience using the equipment."

Montemerlo, M. D. Training Device Design: The Simulation/Stimulation Controversy. Report No. NAVTRAEQUIPCEN-IH-287. Orlando, FL: Naval Training Equipment Center, 1977. (NTIS No. AD-A049 973/1ST)

I. GENERAL SUMMARY OF THE DOCUMENT

A. Focal Industry

Military applications; examples from military and civilian settings including power plants.

B. Type of Document

Review of findings from effectiveness studies of operator training in a variety of fields.

C. Basic Objective(s)

The document looks at the question of the relative effectiveness of two different types of training devices--synthetic and actual equipment trainers.

D. Major Findings or Recommendations

Given that a competent, unbiased training analysis has resulted in the conclusion that practice should be given via a school-based training device, should that device consist of actual equipment, modified actual equipment, synthetic equipment, or a combination? (Nuclear power plant simulators are categorized as synthetic trainers.) Since successes have been reported for both types, the indication is that neither is inherently superior to the other. The report lists seven factors found to affect the relative effectiveness of both trainer types: cost, reliability, maintainability, safety, facility requirements, training features, and modifiability. Examples are given from the fields of: vehicle operator training (pilots, astronauts); equipment operator training (power plants, sonar equipment); and maintenance training. The training program with which a training device is used is more important than the type of device used. State-of-the-art training device technology has far outdistanced existing knowledge as to which device is appropriate. The problem is choosing a device with little knowledge of its relative strengths and weaknesses. Media selection models (for choosing the most appropriate learning medium for a specified training task) have not been validated. Since the process of selecting and designing training devices is judgmental, use should be made of a training device decision team with personnel with expertise in instructional technology, engineering technology, the equipment to be taught, and the procurement process. Such a team is an excellent vehicle for insuring that the device's training potential is fully achieved. The team should:

a. involve the instructors who will be using the device;

b. develop a training program that capitalizes on the device's particular advantages;

c. develop a training program for instructors;

d. develop a training program to move the trainees from the device to the actual equipment;

e. ensure that the device is completely "debugged" before putting it into use;

f. prepare a maintenance program for the device;

g. prepare a modification program to ensure that the device is always kept up to date;

h. ensure that all team programs are adequately documented prior to disbanding.

II. SIMULATOR TOPIC FOCUS

A. Uses of Simulators Addressed

Training, retraining.

B. Types of Simulators Addressed

Synthetic, actual equipment, part-task, procedures, familiarization, egress and generalized trainers and system boards.

III. SIMULATOR FIDELITY

A. Fidelity Dimensions and Definitions

Fidelity not defined in this document. A synthetic trainer for an operational system is defined as a device built to resemble the appearance and operation of that system but does not employ actual hardware. Its parts cannot be interchanged with parts of the operational system. Hybrid trainers consist of both synthetic and actual equipment.

B. Explicit Statement of Required Fidelity Level

None made; depends on detailed training objectives analysis.

C. Variables Affecting Required Fidelity Level

Cost, reliability, maintainability, safety, facility requirements, required training features, and modifiability.

D. Criteria for Determining Required Fidelity Level

See III-C.

E. Methods for Determining Required Fidelity Level

Not specified.

IV. SIMULATORS IN TRAINING SYSTEMS

A. Relationship to Training for Specified Tasks

Training device program should be developed for each specified task.

B. Relationship to Training Effectiveness

Both synthetic and actual equipment devices have been reported to be effective. Training features include: malfunction insertions, automated briefings, automated demonstrations, performance recording and playback, parameter recording automated performance measurement, out-of-tolerance alerts, remedial messages, adaptive training, guided practice, augmented feedback, and quality control for performance criteria.

C. Methods for Establishing Training Effectiveness

Not explicitly addressed.

D. Simulators as Part of Training Systems

Use of an interdisciplinary team to determine: (a) training requirements; (b) existence of aspects of actual operational equipment that might be detrimental to training; (c) feasibility of redesigning the operational system synthetically to eliminate detrimental aspects; and (d) cost-benefit ratio of actual equipment to synthetic trainers to meet specified training requirements.

Morris, R., & Thomas, J. Simulation in training. Parts 1, 2, 3. Industrial Training International, 1976, 11, 66-69, 161-163, 202-204.

I. GENERAL SUMMARY OF THE DOCUMENT

A. Focal industry

Chemical industry.

B. Type of Document

Descriptive article.

C. Basic Objective(s)

Article discusses simulation in training--its benefits and disadvantages; design; relationship to fidelity and training objectives. Specific uses of simulation are discussed. Types of simulation ranging from paper and pencil through digital computer process simulator are described.

D. Major Findings or Recommendations

For some kinds of training, simulation is necessary. Simulation is defined as "the ongoing representation of certain features of a real situation to achieve some specified (training) objective." There is sometimes too much focus on the equipment used; it should be recognized that the purpose of simulators is to meet well-defined training objectives, and effective simulation can sometimes be achieved with equipment as simple as paper and pencil. For any situation in which simulation is considered, it is important to (1) identify individual systems involved (e.g., temporal, technical, environmental); and (2) identify objectives of each system. It is then possible to estimate the appropriate learning medium and degree of fidelity. The authors present a system for classifying training objectives.

Design of good simulation is very difficult. To some extent, it is possible to compensate for weak simulation design by increasing hardware (simulator) dependence, but simulation is only as good as the total training package. Simulation can be classified within a matrix of hardware dependence and software dependence.

II. SIMULATOR TOPIC FOCUS

A. Uses of Simulators Addressed

Training, retraining, instructors' uses, procedure development and testing, enhancement of crew coordination.

B. Types of Simulators Addressed

Full-scale, part-task; paper and pencil; tapes, slides, films; models; small scale training plants; process simulators.

III. SIMULATOR FIDELITY

A. Fidelity Dimensions and Definitions

"The amount of reality which is put into the simulation is a measure of its fidelity"

B. Explicit Statement of Required Fidelity Level

No explicit statement of specific fidelity levels. "Fidelity should be introduced into a simulation only to the extent which is essential for the achievement of training objectives." It may be more important for the simulator to function as the plant than to look like the plant.

C. Variables Affecting Required Fidelity Level

Number of systems involved (e.g., temporal, technical, environmental) and importance of interactions among these systems; training objectives; stress that will be involved when plant goes rapidly off-spec (fidelity of stress representation in training is more important than fidelity of fault symptom representation).

D. Criteria for Determining Required Fidelity Level

Not addressed.

E. Methods for Determining Required Fidelity Level

Not addressed.

IV. SIMULATORS IN TRAINING SYSTEMS

A. Relationship to Training for Specified Tasks

Suggested uses of simulation are: familiarization with process and/or plant; retraining for modified procedures; exploration of plant optimization; training in fault finding, handling emergencies; development of teamwork and skills.

B. Relationship to Training Effectiveness

For some kinds of training simulation is necessary, although the simulator may be very simple (paper and pencil or slides).

Training effectiveness is highly dependent on software supporting simulator and on skill of trainer.

C. Methods for Establishing Training Effectiveness

Not stated.

D. Simulators as Part of Training Systems

It is necessary to have a well-thought-out training objective analysis prior to using simulators.

Mudd, S. Assessment of the fidelity of dynamic flight simulators. Human Factors, 1968, 10(4), 351-358.

I. GENERAL SUMMARY OF THE DOCUMENT

A. Focal Industry

Aviation industry.

B. Type of Document

Journal article; methodological critique.

C. Basic Objective(s)

The evaluation of dynamic flight simulators is considered from the standpoint of the efficiency and validity of the currently used pilot evaluations and assessment techniques.

D. Major Findings or Recommendations

A set of requirements for an ideal fidelity measurement technique is presented, followed by a comparison of the two general approaches to fidelity measurement, the analytic and the empirical. The subjective and partial reproduction characteristics of training simulators lead, respectively, to the empirical and analytic orientation to the fidelity assessment problem. Empirical measures emphasize the essential subjectivity of fidelity evaluation, but lack the sophisticated diagnostic property of formal analysis. Analytic measures have considerable diagnostic potential for the identification of faulty elements of simulation, but do not accommodate subjective data in its presently available forms. A control-recorded discrepancy technique, if it could be implemented, would generate a subjective error signal in a form suitable for analysis by control system methods, particularly those developed for model reference self-adaptive systems. Three major assumptions underlying the feasibility of such a technique do not seem to be too unrealistic: (1) that evaluators of dynamic flight simulators can recognize discrepancies between the performance of the simulator and the remembered performance of the vehicle being simulated; (2) that the evaluator can resolve a configuration of dynamic motion cues into components; and (3) that the evaluator could report apparent motion discrepancies by means of a control type response while actually participating in a simulation exercise.

II. SIMULATOR TOPIC FOCUS

A. Uses of Simulators Addressed

Training.

B. Types of Simulators Addressed

Non-specified, but presumably part-task or full-task aircraft simulators.

III. SIMULATOR FIDELITY

A. Fidelity Dimensions and Definitions

The issue of fidelity of simulation is concerned with the degree of accuracy required of a simulated task, element or situation in reproducing the real counterpart. Since the issue centers around units of accuracy, the resolution of the issue is ultimately dependent upon the techniques available for measuring simulation fidelity. Evaluations of fidelity for simulation training involve measures of the extent to which a simulator reproduces a behavioral environment similar to the relevant aspects of the operational environment being simulated. If similarities between the two types of situation are specified along stimulus-response dimensions the fidelity measure can be related not only to transfer-of-training phenomena, but also to specific aspects of the simulator.

There are two basic characteristics of simulation which condition the requirements for a technique to assess directly the fidelity of a given simulator:

1. Subjective similarity--since the training simulator must elicit accurately the subjective perceptual, cognitive and motor responses that an individual experiences in a corresponding real situation, physical similarity is secondary to psychological similarity. Judgments of fidelity are necessarily subjective in the sense that it is the subjective, behavioral environment that is to be evaluated, not the objective, physical characteristics of the simulation equipment. The essential subjectivity of fidelity judgments does not mean that objective techniques for measurement cannot be developed. Subjective impressions of the realism of the simulator experience can be converted into reliable indices related to the objective, physical variables involved in generating the experience.

2. Partial reproduction--the optimum strategy for simulation design is to reproduce only those aspects of a situation which are relevant to the set of responses involved in the system

being simulated. In some cases it is possible to establish by experiment just which elements of a situation need to be reproduced for accurate behavioral representation.

B. Explicit Statement of Required Fidelity Level

The pilot evaluators need to be provided with a device which is driven by inputs similar or identical to primary flight controls. Given such a device, the simulation evaluation pilot would generate a "discrepancy" control input whenever in the course of a performance test an "untrue" simulator response occurred for the operation required by the test. Error signals in conjunction with other flight records would be subjected to formal analysis by techniques for model referenced self-adaptive systems.

C. Variables Affecting Required Fidelity Level

Individual subjective perceptual, cognitive and motor responses that an individual experiences in the corresponding real situation.

D. Criteria for Determining Required Fidelity Level

A fidelity assessment technique should provide information concerning the general degree of simulation fidelity, and it also should provide some means for establisning which elements of the simulation are missing, di'torted, or misleading.

E. Methods for Determining Required Fidelity Level

Empirical (subjective experience) approach centers around a technique involving the rating of accuracy of simulation by means of pilot commentary and rating scales. Empirically, a simulator is considered to have fidelity to the extent that evaluator ratings are satisfactory and comments are favorable, the analytic approach to fidelity assessment centers around a model-matching procedure in which the dynamics of a given system are represented in the form of equations, the solutions which are to be matched or approximated by the simulator. Analytically, a simulator is considered to have fidelity to the extent that the simulator model generates an output that falls within specified engineering tolerances of the parent model. The translation links between subjective fidelity judgments and engineering analysis are complicated by the problems of translating verbal reports into engineering quantities.

IV. SIMULATORS IN TRAINING SYSTEMS

A. Relationship to Training for Specified Tasks

Transfer-of-training evaluations of training simulators have the advantage of being directly related to the objective of training but have the disadvantage of (a) non-applicability for many complex and advanced systems; (b) no basis for generalization to other systems; and (c) no provision for the type of feedback that facilitates the modification of the simulator being evaluated. Fidelity evaluations have the advantage of being potentially more generalizable and being directly related to simulator characteristics without sacrificing relevance to the transfer-of-training objectives of simulation trainers.

B. Relationship to Training Effectiveness

The position of the practical-minded is that since training programs have the cardinal objective of maximizing positive transfer of experience from training situation to operational situation, units of performance proficiency can be used to assess simulation effectiveness directly without introducing the questions of fidelity.

C. Methods for Establishing Training Effectiveness

Instructor monitor reports, automatic recording of student performance.

D. Simulators as Part of Training Systems

Assumed that simulators have a valuable role within a well-planned training program.

Payne, T. A. Conducting Studies of Transfer of Learning: A Practical Guide. Report No. AFHRL-TR-81-25. Dayton, OH: University of Dayton Research Institute, 1982. (NTIS No. AD-A110 569/1)

I. GENERAL SUMMARY OF THE DOCUMENT

A. Focal Industry

U.S. Air Force.

B. Type of Document

Literature review and applications guide.

C. Basic Objective(s)

The objective of the document is to provide a practical guide for use in conducting studies of the transfer of learning from training in a flight simulator to performance in an aircraft.

D. Major Findings or Recommendations

The approach used is to review published and unpublished information on transfer of learning and experimental design relevant to pilot training. Key issues and factors are identified as well as a sequence of steps to be followed by the practical researcher for the conducting of credible, methodologically unflawed and scientifically valid studies. The report addresses the need for careful planning, definition of the problem and the task, consideration of students, instructors, performance measurement, time requirements, diluting factors, scheduling the study in a busy operational environment, method testing and analysis of results. These issues provide the means by which the researcher can attempt to conduct a study illustrating the maximum possible transfer estimate for the task at hand, illustrating for the operational instructor what can be accomplished.

II. SIMULATOR TOPIC FOCUS

A. Uses of Simulators Addressed

Training, instructors' uses.

B. Types of Simulators Addressed

Non-specific, applies to any type of simulator.

III. SIMULATOR FIDELITY

A. Fidelity Dimensions and Definitions

Not addressed.

B. Explicit Statement of Required Fidelity Level

Not addressed.

C. Variables Affecting Required Fidelity Level

Not addressed.

D. Criteria for Determining Required Fidelity Level

Not addressed.

E. Methods for Determining Required Fidelity Level

Not addressed.

IV. SIMULATORS IN TRAINING SYSTEMS

A. Relationship to Training for Specified Tasks

At the outset, the research team must derive definitions of tasks the students will be expected to perform in the operational situation represented in the study. Although the underlying question concerns the extent to which prelearning on a simulator will transfer to operational performance, the first step should involve consideration of the specific purpose of the particular training transfer study.

B. Relationship to Training Effectiveness

Transfer of learning is defined as any effect of learning resulting from pretraining on a prior task (or set of tasks) upon performance in a subsequent task (or set of tasks). Such transfer effect may not exist at all, might be facilitating or interfering in nature.

C. Methods for Establishing Training Effectiveness

Percent transfer of learning given by either:

1. $\frac{\bar{C} - \bar{X}}{\bar{C}}$ where $\bar{C}$ = Average of trials, time or errors accumulated by a control group to arrive at a performance criterion in the aircraft

$\overline{X}$ = Same measure for experimental group who have been pretrained to a performance criterion on a simulator

2. $\frac{\overline{X} - \overline{C}}{\overline{C}}$ where $\overline{X}$ = Average of grades assigned to experimental students for performance in aircraft

$\overline{C}$ = Same measure for control students

The transfer effectiveness ratio (TER) which measures the amount of simulator pretraining required by an experimental group to evidence superior performance in the aircraft as compared to performance of a control group.

$TER = \frac{\overline{C} - \overline{X}}{S_x}$ where $\overline{C}$ = Average of trials or time required by a control group to arrive at a performance criterion in the aircraft

$\overline{X}$ = Same measure for experimental group pretrained on the simulator

S_x = Average of trials or time required by experimental group to arrive at performance criterion in the simulator

The difference between the estimate of percent transfer of learning and the transfer effectiveness ratio is that the former ignores the amount of pretraining required in the simulator and the latter takes that into account. There may be occasions when it would be of value to use both models in the same study.

D. Simulators as Part of Training Systems

The first step is definition of the immediate training problem. Selection of the task or tasks to be trained is the second step. The third and fourth steps involve the determination of what learners should be involved in the study, then the identification of appropriate performance measures. The fifth and sixth steps are the use of the instructor as a research participant and the assignment of sufficient time for the study. The seventh step involves avoiding factors which may dilute transfer of learning. The final steps include advanced scheduling of the study, testing the methodology before collecting final data, data analysis, and presentation of the results.

Purifoy, G. R., Jr., & Benson, E. W. Maintenance Training Simulators Design and Acquisition: Summary of Current Procedures. Valencia, PA: Applied Science Associates, Inc., 1979. (NTIS No. AD-A079 636/7)

I. GENERAL SUMMARY

A. Focal Industry

U.S. Air Force.

B. Type of Document

Technical report; descriptive.

C. Basic Objective(s)

This document explores the problems of maintenance training simulation design and acquisition.

C. Major Findings or Recommendations

The document focuses on the existing Air Force procedures for instructional systems development analysis for defining maintenance training equipment requirements. Simulation, long an established training technique for systems operators, has a number of potential benefits when applied to teaching of system maintenance: reduced cost, increased training equipment reliability, instructionally effective device characteristics, student and instructor safety when practicing operationally hazardous activities, capability of tailored hands-on practice opportunities through malfunction insertion and the creation of operationally critical and seldom encountered conditions. However, to date the realization of these advantages has not been spectacular. There are no formalized procedures for maintenance simulator design which has resulted in high variability in the cost-effectiveness of current maintenance simulators.

II. SIMULATOR TOPIC FOCUS

A. Uses of Simulator Addressed

Equipment maintenance training.

B. Types of Simulator Addressed

Part-task, whole-task, integrated-task simulators.

III. SIMULATOR FIDELITY

A. Fidelity Dimensions and Definitions

Not addressed.

B. Explicit Statement of Required Fidelity Level

Not made.

C. Variables Affecting Required Fidelity

Thorough task analysis and use of defined Instructional System Development (ISD) system.

D. Criteria for Determining Required Fidelity Level

See III-C.

E. Methods for Determining Required Fidelity Level

Team work by relevant experts.

IV. SIMULATORS IN TRAINING SYSTEMS

A. Relationship to Training for Specified Tasks

Identify skills and knowledge best learned on a specific simulator. Group skills and knowledge by class or type of simulator.

B. Relationship to Training Effectiveness

Specify for each simulator how well associated skills and knowledge must be learned.

C. Methods for Establishing Training Effectiveness

Not addressed.

D. Simulators as Part of Training System

Must be integrated into thoroughly analyzed instructional development system.

Roberts, L. Simulation in training--Part 6: The use of process simulators--a case history--Parts I and II. Industrial Training International, 1976, 11, 293-295, 318-320.

I. GENERAL SUMMARY OF THE DOCUMENT

A. Focal Industry

Chemical industry.

B. Type of Document

Descriptive article.

C. Basic Objective(s)

Part I reports on hardware, set-up, use and problems of Simtran PPS-1 process simulator at Shell Chemicals (UK) 1968-74.

Part II describes hardware, use and problems of Simtran PPS-106 process simulator at Shell Chemicals (UK) 1974-76. The advantages of the PPS-106 over the PPS-1 are described.

D. Major Findings or Recommendations

Process simulators are of greatest value in training for plants with large-scale continuous processes (e.g., petrochemical plants). Breakdown of processes into sections may be advantageous for training, but it is important to provide continuity of operation of the various sections. Training is best done one student at a time, although usually there are four to six trainees in a group. The training method used on the Simtrans by Shell was "training by doing"; often trainee errors were left uncorrected by the instructor, so that results could be observed by the trainee. The speed of process response to trainee action should be realistic. Simulation of plant responses by programming (PPS-106) rather than by instructor actions (PPS-1) was advantageous. It gave more realism and it freed instructor time for attention to trainees.

II. SIMULATOR TOPIC FOCUS

A. Uses of Simulators Addressed

Training and retraining of operators; procedure development and testing; training of instrument mechanics; improvement of crew coordination.

B. Types of Simulators Addressed

Process: full-scale, part-task.

III. SIMULATOR FIDELITY

A. Fidelity Dimensions and Definitions

Not addressed.

B. Explicit Statement of Required Fidelity Level

Not addressed.

C. Variables Affecting Required Fidelity Level

Not addressed.

D. Criteria for Determining Required Fidelity Level

Not addressed.

E. Methods for Determining Required Fidelity Level

Not addressed.

IV. SIMULATORS IN TRAINING SYSTEMS

A. Relationship to Training for Specified Tasks

Simulation is especially effective in training for continuous process plant operation. When plants run continuously for long periods, experience in start-up and shut-down may be available only on a simulator. Training for batch process operations, on the other hand, may be more cost-effective on actual plants.

B. Relationship to Training Effectiveness

Simulation is essential for some kinds of training, such as for operation of large-scale continuous chemical process plants.

C. Methods for Establishing Training Effectiveness

Not addressed.

D. Simulators as Part of Training Systems

Support is given to the idea that simulators are just a part of the training system. It is suggested that increased automatic functioning of simulators is advantageous partly because it frees instructors for individual attention to trainees.

Reason, J. Full-scope simulators: "ital tools for nuclear training. Power, 1979, 123(7), 33-39.

I. GENERAL SUMMARY

A. Focal Industry

Nuclear power.

B. Type of Document

Descriptive.

C. Basic Objective(s)

The article directly deals with the use of simulators for the training of nuclear power plant operators. The article describes in a general way the history of simulator development, the process of manufacture and the way they are used in training.

D. Major Findings or Recommendations

The intent of the article is to report the increased capabilities of the latest simulators, the pay-offs to the utilities of simulator use and the very strong demand for their use and construction. The article contains a brief description of a malfunction exercise carried out on a simulator.

II. SIMULATOR TOPIC FOCUS

A. Uses of Simulators Addressed

Hot-, cold-, licensing, requalification, retraining.

B. Types of Simulators Addressed

Very high-fidelity full scope simulators.

III. SIMULATOR FIDELITY

A. Fidelity Dimensions and Definitions

Not directly addressed.

B. Explicit Statement of Required Fidelity Level

As stated in existing NRC regulations and ANS 3.5 suggested standards.

C. Variables Affecting Required Fidelity Levels

Regulations, cost, access to simulator trainers.

D. Criteria for Determining Required Fidelity Level

Same as III-C.

E. Methods for Determining Required Fidelity Level

Not addressed.

IV. SIMULATORS IN TRAINING SYSTEMS

A. Relationship to Training for Specified Tasks

Simulator suitable for all tasks related to reactor operation.

B. Relationship to Training Effectiveness

The possible requirement of a training simulator to duplicate every future nuclear plant has been mentioned. But there is considerable debate as to how much actual value this would have in increased plant operation safety. An important aspect of training is that the operators learn to be able to look at the complete plant on the basis of engineering fundamentals. While a simulator may help them to do this, improper use by the instructor may place too much emphasis on following procedures by rote. This is important for maximum efficiency during normal plant operations, but may be detrimental during emergency procedures. The simulator is only a tool, and the value of the training on it is determined largely by the skill and ingenuity of the instructor.

C. Methods for Establishing Training Effectiveness

Not addressed.

D. Simulators as Part of Training Systems

Economic incentives for buying a simulator along with each reactor unit are convincing. If two or more identical units are being built, the benefits appear almost overwhelming. However, the purchase and operation of a simulator is only part of the total training cost. Utilities are not necessarily in the best position to operate training programs and may prefer to send their operators to programs run by reactor manufacturers or independent organizations. The biggest benefit of an on site simulator and training center is availability. It is assumed that quality of training is directly proportional to time spent on the simulator. While nuclear safety was the original spur to the development of full-scale power plant training simulators, these systems have since proved their economic viability. Utilities have found advantages over and above safety, and this has been demonstrated by the spread of full-scale training simulators to fossil-fueled power plants.

Saastamoinen, J. Training simulators for nuclear power plants. Kernenergie, 1976, 19(8), 237-241.

I. GENERAL SUMMARY OF THE DOCUMENT

A. Focal Industry

Nuclear industry.

B. Type of Document

Descriptive article.

C. Basic Objective(s)

The paper discusses uses and building of nuclear power plant simulators (NPPSs). The scope, benefits and uses of simulators, as well as their role in operator training programs, are discussed. Computer hardware and software, and ways of decreasing their costs, are described.

D. Major Findings or Recommendations

The necessity of using NPPSs for operator training is assumed. Two types of simulators, the principle training and the full-scope, are discussed. (The principle training simulator models basic plant energy production cycles, with a minimal representation of peripheral systems.) "The scope of a nuclear power plant training simulator depends on the objective set as to the training to be given by the simulator."

Main reasons for use of NPPSs are training efficiency and economics. NPPSs can be useful not only for training and retraining, but also for debugging and development of operational procedures, verification of plant design, testing of plant computer systems, and study of data display formats.

Initial training programs can use both principle training and full-scope simulators; retraining can use full-scope.

Hardware requirements of principle training and full-scope simulators are described. For full-scope training simulators, the computer system must be able to handle input/output signals of the following quantities: digital input, 1000-2500; digital output, 1500-6000; analog input, 10-500; analog output, 300-1000. For principle training simulators, input/output signals number a few hundred.

"The most critical element in developing a training simulator lies in the software." Relative cost of software to hardware is increasing. Total software expense can be decreased by the use of generalized model program packages. Requirements of software are described. Results for full-scope training simulators must be functionally correct to the extent that operators cannot tell the difference between simulator and real plant. In modeling a sequence of events, the operator's limit of resolution is about 0.3 second.

II. SIMULATOR TOPIC FOCUS

A. Uses of Simulators Addressed

Generally: training, requalification training, instructors' uses, familiarization of management, license examination. Principle training simulators: initial training program connected with courses in nuclear technology fundamentals; education of plant design personnel toward overall understanding of plant behavior; augmentation of university courses in nuclear engineering and power plant technology. Full-scope: debugging and development of operational procedures; verification of plant design; testing of plant computer system; study of data display formats.

B. Types of Simulators Addressed

Full-scope, part-task (principle training); dynamic.

III. SIMULATOR FIDELITY

A. Fidelity Dimensions and Definitions

Not addressed.

B. Explicit Statement of Required Fidelity Level

Simulated order of events needs to be correct only to about 0.3 second, the operator's resolution capability limit.

C. Variables Affecting Required Fidelity Level

See III-D.

D. Criteria for Determining Required Fidelity Level

"In excluding systems [from full-scope training simulators] one must be very careful that the training value and realism will not be essentially reduced. Therefore, a really full-scope simulator could be the best solution from the cost-performance point of view."

"In the case of a full scope training simulator the design criterion for the models is that their results are functionally correct to the extent that an experienced operator cannot recognize differences, from the operator's point of view, between the simulator and the real plant. No absolute values as to required accuracy can be defined which would be reasonable in all circumstances."

E. Methods for Determining Required Fidelity Level

Not addressed.

IV. SIMULATORS IN TRAINING SYSTEMS

A. Relationship to Training for Specified Tasks

Scope of simulator training is much wider in training for disturbances than in training for normal situations.

B. Relationship to Training Effectiveness

"The use of training simulators instead of real plants is motivated by the superiority as to training effectiveness and economics. The higher efficiency results from the increased accessibility, wider scope and extra training features provided."

C. Methods for Establishing Training Effectiveness

Not addressed.

D. Simulators as Part of Training Systems

Principle simulators can be used in initial training. Full-scope simulators can be used in initial training and in retraining.

Semple, C. A. Simulator Training Requirements and Effectiveness Study (STRES): Executive Summary. Report No. AFHRL-TR-80-63. Westlake Village, CA: Canyon Research Group, Inc., 1981. (NTIS No. AD-A094 381)

I. GENERAL SUMMARY OF THE DOCUMENT

A. Focal Industry

U.S. Air Force.

B. Type of Document

Document summarizes six technical reports (see Section V of this entry for list of reports summarized).

C. Basic Objective(s)

Primary objectives for the research include: criteria for matching training requirements with aircraft simulator fidelity features; criteria for matching simulator instructional features with specific training requirements; principles of effective and efficient utilization of simulators to accomplish specific training requirements; models of factors influencing the life-cycle cost and worth of ownership of simulators.

D. Major Findings or Recommendations

The report concludes that the scientific literature cannot be directly applied to the research questions raised regarding actual correlation between various aspects of fidelity and training effectiveness or operational performance.

II. SIMULATOR TOPIC FOCUS

A. Uses of Simulators Addressed

Training.

B. Types of Simulators Addressed

Part-task and whole-task, high-fidelity, procedures and familiarization trainers.

III. SIMULATOR FIDELITY

A. Fidelity Dimensions and Definitions

Fidelity is the degree to which cue and response capabilities allow for learning and practice of specific tasks so that what is learned will enhance performance of tasks in the operational environment. Dimensions of fidelity addressed: visual system, flight characteristics fidelity, platform motion systems, force-cueing devices, visual and motion systems interactions.

B. Explicit Statement of Required Fidelity Level

Stated to be unknown.

C. Variables Affecting Required Fidelity Level

Type of task, pilot experience, pilot skill level.

D. Criteria for Determining Required Fidelity Level

Not specified.

E. Methods for Determining Required Fidelity Level

Question not addressed directly. General approach is what is the transfer effectiveness of a given piece of training equipment. Experiment then uses experimental and control group.

IV. SIMULATORS IN TRAINING SYSTEMS

A. Relationship to Training for Specified Tasks

Training value of a simulator tied to the training objective and the type of task to be mastered.

B. Relationship to Training Effectiveness

Results anecdotal and non-generalizable.

C. Methods for Establishing Training Effectiveness

Transfer effectiveness ratio, time to reach criterion level of performance.

D. Simulators as Part of Training Systems

Simulator instructor training is central to effective and efficient simulator use. Need for improved instructor training emphasizing principles of instruction and use of simulators as flexible training tools.

V. REPORTS COVERED BY THE EXECUTIVE SUMMARY

Allpee, K. E., & Semple, C. A. Aircrew Training Devices: Life Cycle Cost and Worth of Ownership. AFHRL-TR-80-34. Wright-Patterson Air Force Base, OH: Air Force Human Resources Laboratory, January 1, 1981.

Caro, P. W., Shellnutt, J. B., & Spears, W. D. Aircrew Training Devices: Utilitzation. AFHRL-TR-80-35. Wright-Patterson Air Force Base, OH: Air Force Human Resources Laboratory, January 1, 1981.

Prophet, W. W., Shellnut, J. B., & Spears, W. D. Simulator Training Requirements and Effectiveness Study (STRES): Future Research Plans. AFHRL-TR-80-37. Wright-Patterson Air Force Base, OH: Air Force Human Resources Laboratory, January 1, 1981.

Semple, C. A., Cotton, J. C., & Sullivan, D. J. Aircrew Training Devices: Instructional Support Features. AFHRL-TR-80-58. Wright-Patterson Air Force Base, OH: Air Force Human Resources Laboratory, January 1, 1981.

Semple, C. A., Hennessy, R. T., Sanders, M. S., Cross, B. K., Beith, B. H., & McCauley, M. E. Aircrew Training Devices: Fidelity Features. AFHRL-TR-80-36. Wright-Patterson Air Force Base, OH: Air Force Human Resources Laboratory, January 1, 1981.

Spears, W. D., Sheppard, H. J., Roush, M. D., & Richetti, C. L. Simulator Training Requirements and Effectiveness Study (STRES): Abstract Bibliography. AFHRL-TR-80-38. Wright-Patterson Air Force Base, OH: Air Force Human Resources Laboratory, January 1, 1981.

Stammers, R. B. Simulation in Training for Nuclear Power Plant Operators. Report No. 12. Karlstad, Sweden: Ergonomraad AB, 1979.

I. GENERAL SUMMARY OF THE DOCUMENT

A. Focal Industry

Nuclear power plant industry.

B. Type of Document

Descriptive, technical report of literature review.

C. Basic Objective(s)

Reviews need for simulation in NPP operator training. Reviews information on degree of fidelity required. Training research is outlined and future directions for study are sketched.

D. Major Findings or Recommendations

The need for simulation in operator training has clearly been demonstrated. The real situation/plant is not necessarily the best one for training or learning. While use of high fidelity simulators does contain training advantages, it avoids the main issue of determining what makes training effective and assessing the potential value of alternative training media including simulators of reduced scale and fidelity.

Effectiveness of training might be improved by integration of full range of training activities from induction lectures through on-the-job training and retraining.

Results of research on training in general process control should be assessed for its application to the nuclear industry. Instructional potential of computer developments to aid instructors should be assessed.

II. SIMULATOR TOPIC FOCUS

A. Uses of Simulators Addressed

Training, instructor's uses, retraining.

B. Types of Simulators Addressed

Full-scale, less than full-scale.

III. SIMULATOR FIDELITY

A. Fidelity Dimensions and Definitions

Not addressed.

B. Explicit Statement of Required Fidelity Level

Not presented, only general inferences from reviewed literature.

C. Variables Affecting Required Fidelity Level

Degree of transfer of learning to job performance; use of simulator, e.g., basic training, licensing or retraining; experience of simulator user; task demands, e.g., learning procedural tasks, failure diagnosis/diagnostic tasks; optimal learning environments.

D. Criteria for Determining Required Fidelity Level

Unknown.

E. Methods for Determining Required Fidelity Level

Use of high fidelity device as ultimate measuring device of required performance for comparison with performance after use of reduced scale simulators.

IV. SIMULATORS IN TRAINING SYSTEMS

A. Relationship to Training for Specified Tasks

Support for importance of relationship, generalities only--nothing specific quoted.

B. Relationship to Training Effectiveness

Unknown, needs research.

C. Methods for Establishing Training Effectiveness

No specific methods stated.

D. Simulators as Part of Training Systems

Integration into a total instructional control system.

Toomepuu, J. Army Flight Simulator Programs from the User's Viewpoint. Fort Eustis, VA: U.S. Army Training Support Center, 1976. (NTIS No. AD-A029 266/4ST)

I. GENERAL SUMMARY OF THE DOCUMENT

A. Focal Industry

Military flight industry.

B. Type of Document

Descriptive article.

C. Basic Objective(s)

The article reviews three subjects: (1) user evaluation of quality and appropriateness of the army flight simulator program; (2) cost-effectiveness of flight simulators; and (3) research necessary to fulfill army flight training needs.

D. Major Findings or Recommendations

The participation of users in army aviation training device R&D has been insufficient and ineffective, in spite of formal procedures for participation. Reasons include inadequate understanding by users of development procedures and lack of special expertise needed to participate in the process.

Cost-effectiveness of army training systems has not been demonstrated. There is a need for methods of measuring Transfer of Training (TOT) effectiveness, that are based on task analysis, that identify cues pilots use to perform these tasks, and that match cue elements with flight simulator subsystems.

New research to investigate flight simulator training capabilities and resource requirements is proposed in the context of (1) future aircraft and organizations; (2) operational doctrine and tactics; and (3) management of aviation training assets. (A list of more specific research proposals is included in the article.)

II. SIMULATOR TOPIC FOCUS

A. Uses of Simulators Addressed

Training; retraining; measurement of skill level of pilots to assess combat-preparedness.

B. Types of Simulators Addressed

Not explicitly stated, but full-scale, part-task, dynamic implied.

III. SIMULATOR FIDELITY

A. Fidelity Dimensions and Definitions

Not addressed.

B. Explicit Statement of Required Fidelity Level

Not addressed.

C. Variables Affecting Required Fidelity Level

Not addressed.

D. Criteria for Determining Required Fidelity Level

Not addressed.

E. Methods for Determining Required Fidelity Level

In general: task analysis, identification of cues used by pilots, match of cue elements with elements of simulator subsystems, user input, cost-effectiveness studies.

IV. SIMULATORS IN TRAINING SYSTEMS

A. Relationship to Training for Specified Tasks

The article discusses some problems of designing simulators to train army pilots for specific tasks such as flying nap-of-the-earth (NOE).

B. Relationship to Training Effectiveness

Many aviation training requirements can be accomplished best, or solely, in simulators. As of 1975, few training cost-effectiveness ratios were employed in military departments, so no quantitative assessment could be made of current vs. alternative philosophies, methods, procedures, equipment and goals. Studies generally assume that one hour in a simulator is equivalent to one hour in the aircraft, but this assumption is not valid. "We need to develop a methodology for measuring transfer of training effectiveness of flight simulators that is based on task analysis, identifies the cues required by pilots to perform tasks, and matches cue elements with the elements of the simulator subsystems that provide the cues. Only then can we proceed to measure the contribution of specific parts of the simulator to transfer of training by selectively isolating and neutralizing elements, while keeping in mind that successive increments of training yield diminishing transfer of training."

C. Methods for Establishing Training Effectiveness

Effective user input needs to be increased; the user is the final judge. Task analysis is the groundwork for evaluating quality, appropriateness and cost-effectiveness of flight simulator training programs.

D. Simulators as Part of Training Systems

Flight simulators need to be developed in the context of the overall training system. "The training value of simulators is primarily determined by how they are used. Our basic need is to improve the effectiveness of simulator use by developing training strategies and programs that help us to realize the full potential of the simulator."

Waag, W. L. <u>Training Effectiveness of Visual and Motion Simulation.</u> Report No. AFHRL-TR-79-72. Brooks Air Force Base, TX: HQ Air Force Human Resources Laboratory, 1981. (NTIS No. AD-A094 530/3)

I. GENERAL SUMMARY OF THE DOCUMENT

A. Focal Industry

U.S. Air Force.

B. Type of Document

Literature review.

C. Basic Objective(s)

Literature concerning the training effectiveness of visual and motion simulation is reviewed. The review focuses on data obtained through application of transfer-of-training methodology.

D. Major Findings or Recommendations

The results are discussed in terms of study design factors: research objectives, experimental design and control, proficiency assessment, sample size, task selection, generalizability, fidelity.

The conclusion is that although there exists much pilot-opinion and in-simulator performance data, their extrapolation to training effectiveness information is questioned. Recommendations for further research needs are made.

With respect to fidelity, the question of "how much fidelity" remains unanswered because of the lack of information on the relationship between degree of fidelity and the amount of training transfer. Because of the current inability to match training requirements and degree of fidelity, it is likely that simulators will continue to be procured under the design goal of maximum fidelity without regard to cost-effectiveness.

II. SIMULATOR TOPIC FOCUS

A. Uses of Simulators Addressed

Training

B. Types of Simulators Addressed

Part-task and whole-task.

III. SIMULATOR FIDELITY

A. Fidelity Dimensions and Definitions

Not addressed.

B. Explicit Statement of Required Fidelity Level

None made.

C. Variables Affecting Required Fidelity Level

Not addressed.

D. Criteria for Determining Required Fidelity Level

Generalizability, transfer-of-training effectiveness, proficiency assessment, sample size, task selection, cost-effectiveness.

E. Methods for Determining Required Fidelity Level

Transfer-of-training experiments with experimental and control groups.

IV. SIMULATORS IN TRAINING SYSTEMS

A. Relationship to Training for Specified Tasks

For most transfer-of-training evaluations of simulators, the selection of tasks does not present a major problem. In most industries, instructors use the simulator to subjectively determine which tasks can be realistically duplicated. Based on these opinions, a training syllabus is developed and subsequently evaluated.

B. Relationship to Training Effectiveness

Taken at face value, the literature suggests that the enhancement of visual simulation will improve the training value of a simulator, whereas addition of a platform motion system will have little effect. However, there are dangers in trying to draw conclusions from diverse and often unrelated research studies. In many cases, study goals are different, and the experimental design and measurements are different. Each of these factors will have a usually unknown effect on the study outcome.

C. Methods for Establishing Training Effectiveness

Instructor evaluations, automatic performance measurements.

D. Simulators as Part of Training Systems

Not explicitly addressed.

Section
B

2. SECTION B. COMPREHENSIVE BIBLIOGRAPHY

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This document contains a comprehensive bibliography on the topic of simulator fidelity and training effectiveness, prepared during the preliminary phases of work on an NRC-sponsored project on the Role of Nuclear Power Plant Simulators in Operator Licensing and Training. Section A of the document is an annotated bibliography consisting of articles and reports with relevance to the psychological aspects of simulator fidelity and the effectiveness of training simulators in a variety of settings, including military. The annotated items are drawn from a more comprehensive bibliography, presented in Section B, listing documents treating the role of simulators in operator training both in the nuclear industry and elsewhere.

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