Technical Report 545

TRAINING SIMULATOR FIDELITY GUIDANCE: THE ITERATIVE DATA BASE APPROACH

Robert T. Hays

SIMULATION SYSTEMS TECHNICAL AREA

U. S. Army
Research Institute for the Behavioral and Social Sciences

September 1981

U. S. ARMY RESEARCH INSTITUTE
FOR THE BEHAVIORAL AND SOCIAL SCIENCES

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NOTICES

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: Technical Report 545	2. GOVT ACCESSION NO.: AD-A119151
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): Training Simulator Fidelity Guidance: The Iterative Data Base Approach	5. TYPE OF REPORT & PERIOD COVERED: Technical Report, September 1981
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Robert T. Hays	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: US Army Research Institute for the Behavioral and Social Sciences (PERI-IE), 5001 Eisenhower Ave Alexandria, Virginia 22333	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 2Q162717A790
11. CONTROLLING OFFICE NAME AND ADDRESS: US Army Research Institute for the Behavioral and Social Sciences(PERI-IE), 5001 Eisenhower Ave Alexandria, Virginia 22333	12. REPORT DATE: September 1981
	13. NUMBER OF PAGES: 33
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Simulation training
simulators
simulator fidelity
fidelity guidance
fidelity requirements
fidelity research

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This paper provides a preliminary organizational framework for a training simulator fidelity data base. Such a data base can provide a starting point for the development of a formal training simulator fidelity decision making package and can also be the basis for the determination of future research. The organizational structure of the data base is developed in three stages. First, the issue of determining the minimum required fidelity for a training simulator is located in its place within the context of the ISD process.

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Secondly, the necessary informational inputs to the fidelity decision process from task analyses are discussed with the goal of obtaining more useful information for making fidelity decisions. Finally, a proposed structure for making fidelity decisions and for conducting future research is presented. This structure is derived from the use of a proposed iterative data base of empirically derived data on the relationship between simulator fidelity and training effectiveness.

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Department of the Army

September 1981

Army Project Number
2Q162717A790

Human Performance Effectiveness
and Simulation

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FOREWORD

The Simulation Systems Technical Area of the Army Research Institute for the Behavioral and Social Sciences (ARI) performs research and development in areas that include training simulation with applicability to military training. Of special interest is research in the area of simulation fidelity requirements. It is necessary to determine the required levels of simulator fidelity before any training system may be developed and procured for use in the Army training community.

This report provides a preliminary organizational framework for a training simulator fidelity data base which can provide guidance in making fidelity decisions and also aid in planning future research efforts.

Further development of the ideas in this report will lead to production of user-oriented guidelines for making training simulator design decisions by training device procurers such as the Project Manager for Training Devices (PM TRADE) and users such as the Army training community.

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TRAINING SIMULATOR FIDELITY GUIDANCE: THE ITERATIVE DATA BASE APPROACH

BRIEF

REQUIREMENTS:

To provide a preliminary organizational framework for a training simulator fidelity data base which can serve two major functions. It can provide a starting point for the development of a formal training simulator fidelity decision making package and can also be the basis for the determination of future research.

PROCEDURE:

The organizational structure for a training simulator fidelity data base was developed in three stages: First, the issue of determining the minimum required fidelity for a training simulator is located in its proper place within the context of instructional systems development (ISD). Secondly, the necessary informational inputs to the fidelity decision process from task analysis were discussed with the goal of obtaining task analysis information which will be useful in making fidelity decisions. Finally, a proposed structure for making fidelity decisions and for conducting future research was presented. This structure is derived from the use of a proposed iterative data base of empirically derived data on the relationship between simulator fidelity levels and training effectiveness.

FINDINGS:

Guidance for making training simulator fidelity decisions may be provided by consulting a data base which consists of the latest empirical data on the relationship between levels of training simulator fidelity and training effectiveness. The data base should be iterative in nature with new data added as it is empirically collected. It should include data on all interactive variables which affect this relationship.

UTILIZATION OF FINDINGS:

This report may be used by researchers in planning for research on the relationship between training simulator fidelity and training effectiveness and also as a means of organizing existing data on this relationship to provide guidance for making fidelity decisions.

TRAINING SIMULATOR FIDELITY GUIDANCE: THE ITERATIVE DATA BASE APPROACH

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TRAINING SIMULATOR FIDELITY GUIDANCE: THE ITERATIVE DATA BASE APPROACH

High technology has brought mixed blessings to the training community. New systems, which use modern high technology components, are highly efficient, but are also expensive, complex and difficult to operate and maintain. This complexity has led to diverse problems when it comes to training personnel to work with these systems. This is true in all areas of society and is especially true in the military. Complex military weapon systems must be operated and maintained and the training of personnel to work these systems is becoming a growing problem. More and more reliance is being placed on training devices and simulators in the military training program. Among the many reasons for this reliance is the fact that simulators can train many tasks more effectively and at a lower cost than actual equipment trainers (Spangenberg, 1976, discusses the unique advantages of simulation for training). Before simulators can do their job effectively they must be designed, constructed and integrated into a training curriculum. In the process of designing simulators, a crucial decision that must be made is the degree of fidelity that will be incorporated into the simulator. Basically, simulator fidelity refers to the similarity between the simulator and the actual equipment that it simulates (this definition will be elaborated below). It is crucial that the appropriate level(s) of fidelity be determined for a simulator not only to ensure the most effective training, but also because higher levels of fidelity usually mean more money will be spent to develop and construct the simulator. Instructional technologists lack specific guidance to aid them in the determination of appropriate levels of fidelity in the design of simulators for particular training tasks. Therefore, the typical approach is to design a training simulator with as high a fidelity level as one's budget will allow. Lacking empirical data which demonstrates the minimum required fidelity for adequate training, this "shotgun" approach has been the only alternative. Research is needed to empirically determine the minimum required fidelity for any training simulator.

Data on the relationship between fidelity levels and training effectiveness must be collected, but to enhance the efficiency of this research a framework for organizing these data and establishing the priorities for research must first be determined. Only if empirical data are coherently organized can they be used as guidance in specifying the actual configuration of training simulators. This paper attempts to provide a preliminary organizational framework for a fidelity data base. Such a data base can serve two major functions. It can provide a starting point for the development of formal guidance to support fidelity decisions and can also be the basis for the determination of future research. The paper proceeds in three stages. First, the issue of determining the minimum required fidelity for a training simulator will be located in its proper place within the context of Instructional Systems Development (ISD). Secondly, the necessary informational inputs to the fidelity decision process will be discussed. These inputs should be derived from a task analysis, which is structured with this end in mind if it is to provide useful information for the specification of training simulator design. Finally, a proposed structure for making fidelity decisions will be presented. This structure is intended to be heuristic and to serve as an aid in determining the fidelity issues which require empirical investigation. It may also serve as an aid in accumulating the data derived from empirical research efforts into a data base which can become the foundation for specific guidance in making fidelity determinations. This data base should be derived from past as well as future research on the effects of training simulator fidelity on training effectiveness. The construction of the data base should be an iterative process, with refinements provided as new data are accumulated. Before beginning a discussion of the proposed iterative fidelity data base it will be helpful to discuss, in greater detail, the concept of training simulator fidelity.

TRAINING SIMULATOR FIDELITY: A WORKING DEFINITION

A useful framework for organizing research on training simulator fidelity requirements must start with a definition of the term training simulator fidelity. In a previous paper (Hays, 1980) this author discussed the conceptual problems with the term fidelity. There has been a wide variety of definitions of fidelity and a definition which focuses on the physical and functional characteristics of the training simulator was proposed. This paper will use that definition with some slight modifications for clarity. The definition states that:

> Training simulator fidelity is the degree of similarity between the simulator and the equipment which is simulated. It is a two dimensional measurement of this similarity in terms of (1) the physical characteristics, of the simulator and (2) the functional characteristics (i.e., the informational or stimulus and response options) of the simulated equipment.

Let us look at the implications of this definition. Determining the physical and functional characteristics of a simulator is essentially an engineering problem since engineers write the specifications which are used to actually construct a simulator. However, the guiding force behind the determination of these specifications must be the training effectiveness of the simulator (Kinkade & Wheaton, 1972; Bunker, 1978; Hays, 1980). Engineers need guidance to ensure that their training device specifications will be based on training principles which will maximize the training effectiveness. Thus, as instructional systems developers we must analytically and empirically determine how device characteristics (fidelity) affect the training effectiveness of a training simulator. We must then determine the minimum required fidelity to train our tasks effectively and use this as the basis for specifying the characteristics to be incorporated into the training simulator by the engineers. To accomplish this mission, effective guidance is necessary to aid in making these fidelity decisions. Before discussing the specifics of such guidance, the fidelity question must be located in the larger context of instructional systems development (ISD).

TRAINING SIMULATOR FIDELITY DECISIONS IN THE ISD CONTEXT

The ISD process consists of techniques and procedures for both developing and conducting training. Specifying training simulator fidelity is just one portion of this process. The interservice version of ISD (TRADOC, 1975) consists of five phases. Table 1 contains a listing and description of these five ISD phases. Each of these phases consists of a number of blocks which in turn, consist of several steps. Figure 1 shows the blocks making up each of the five ISD phases. The job of determining the level of training simulator fidelity occurs in block III.2: Specify Institution Management Plan and Delivery System. This block includes the activities that select the medium for instructional delivery and specification of the configuration of the instructional medium. Assuming that the chosen medium is a training simulator, the specification of its physical and functional characteristics (i.e., its fidelity) must be determined during this stage of the ISD process. As can be noted from Figure 1 none of the blocks within the five ISD phases occurs in isolation. Each stage used information gathered earlier in the ISD process and the whole process is iterated as new information if earlier blocks are guided by the informational requirements of later blocks. In this case, the necessary inputs for determining the configuration of a training simulator begin with a job-task analysis.

Task analysis has been recognized as the important first step in the development of instructional systems by several researchers (Annett & Duncan, 1967; Smode, 1971; Goldstein, 1974; Mechner, 1981). According to these authors, without a thorough understanding of the task to be trained, it is impossible to design a training curriculum (including the use of simulators or other training devices) that will be effective at training the skills and knowledges that are necessary for the task at hand. In the following section, task analysis is discussed as the input to all subsequent ISD decisions but more specifically as input to the determination of training simulator fidelity.

TASK ANALYSIS

Upon what information do engineers base their decisions on the specifications of a training simulator? Typically, the "rule" has been to buy as much fidelity as the budget will allow. The information from a detailed task analysis is rarely used. The task analysis is normally performed and may even be used in the media selection stage o the ISD process. However, no systematic guidance exists to translate task analysis information into a form which can facilitate fidelity decisions. This section examines the task analysis procedure itself to determine how this important task analysis input may be utilized more effectively to determine the fidelity of training simulators.

Task Analysis: Preliminary Definitions

It may be taken as given that if we are to train someone we must train them to do some kind of task. "A task consists of a series of goal-directed

TABLE 1

The 5 Phases of the ISD Process (TRADOC, 1975)

PHASE I **ANALYZE**	Inputs, processes and outputs in Phase I are all based on job information. An inventory of job tasks is compiled and divided into two groups: tasks not selected for instruction and tasks selected for instruction. Performance standards for tasks selected for instruction are determined by interview or observation at job sites and verified by subject matter experts. The analysis of existing course documentation is done to determine if all or portions of the analysis phase and other phases have already been done by someone else following the ISD guidelines. As a final analysis phase step, the list of tasks selected for instruction is analyzed for the most suitable instructional setting for each task.
PHASE II **DESIGN**	Beginning with Phase II, the ISD model is concerned with designing instruction using the job analysis information from Phase I. The first step is the conversion of each task selected for training into a terminal learning objective. Each terminal learning objective is then analyzed to determine learning objectives and learning steps necessary for mastery of the terminal learning objective. Tests are designed to match the learning objectives. A sample of students is tested to insure that their entry behaviors match the level of learning analysis. Finally, a sequence of instruction is designed for the learning objectives.
PHASE III **DEVELOP**	The instructional development phase begins with the classification of learning objectives by learning category so as to identify learning guidelines necessary for optimum learning to take place. Determining how instruction is to be packaged and presented to the student is accomplished through a media selection process which takes into account such factors as learning category and guideline, media characteristics, training setting criteria, and costs. Instructional management plans are developed to allocate and manage all resources for conducting instruction. Instructional materials are selected or developed and tried out. When materials have been validated on the basis of empirical data obtained from groups of typical students, the course is ready for implementation.
PHASE IV **IMPLEMENT**	Staff training is required for the implementation of the instructional management plan and the instruction. Some key personnel must be trained to be managers in the specified management plan. The instructional staff must be trained to conduct the instruction and collect evaluative data on all of the instructional components. At the completion of each instructional cycle, management staff should be able to use the collected information to improve the instructional system.
PHASE V **CONTROL**	Evaluation and revision of instruction are carried out by personnel who preferably are neither the instructional designers nor the managers of the course under study. The first activity (internal evaluation) is the analysis of learner performance in the course to determine instances of deficient or irrelevant instruction. The evaluation team then suggests solutions for the problems. In the external evaluation, personnel assess job task performance on the job to determine the actual performance of course graduates and other job incumbents. All collected data, internal and external, can be used as quality control on instruction and as input to any phase of the system for revision.

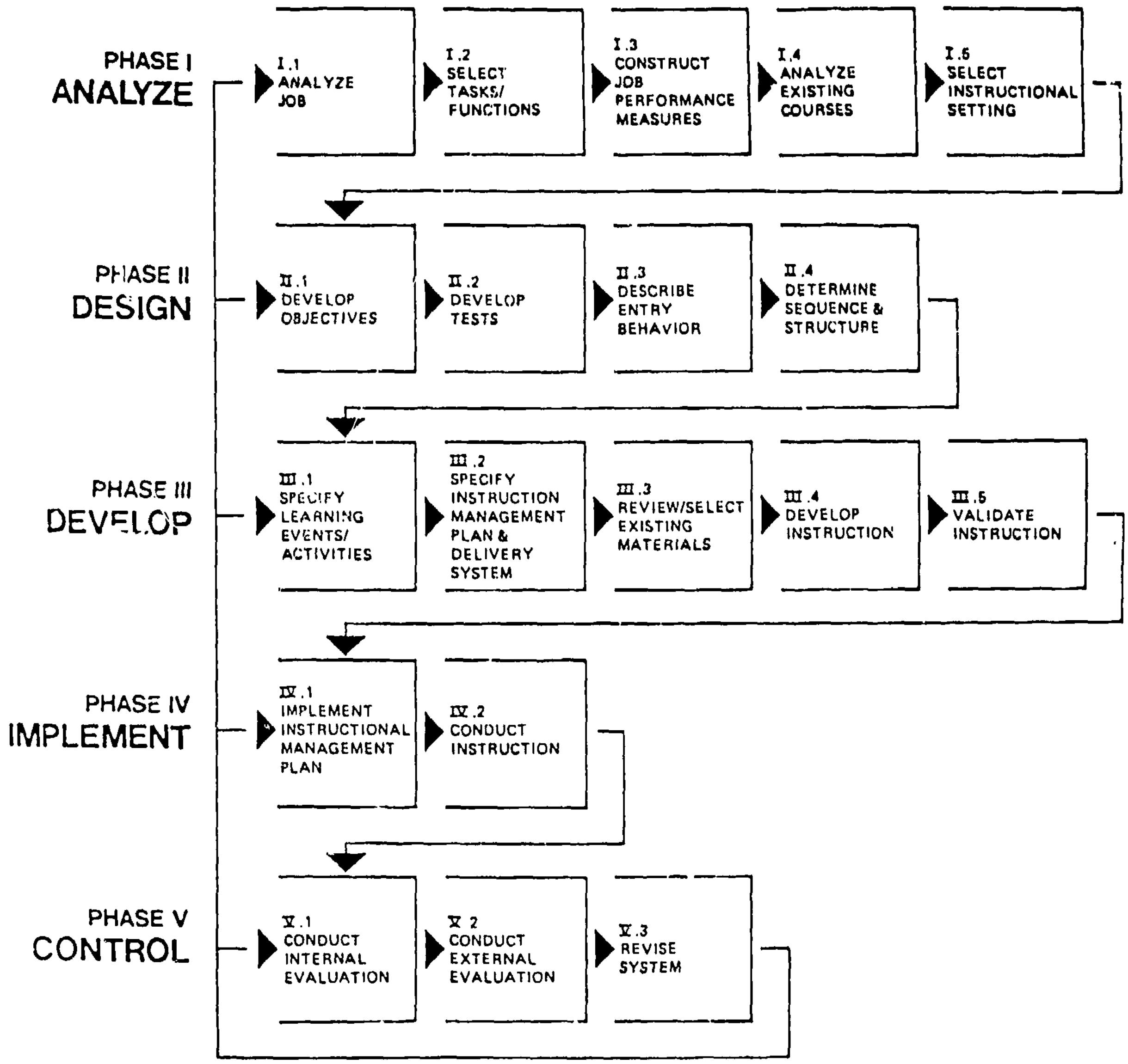

Figure 1. Blocks Within Each Phase of the ISD Process (TRADOC, 1975)

transactions controlled by one or more 'programs' that guide the operations by a human operator of a prescribed set of tools through a set of completely or partially predicted environmental states" (Miller, 1971b, p.11). According to Miller (1962), each task consists of: (1) an indicator on which the activity-relevant indication appears, (2) the indication or cue which calls for a response, (3) the control object to be activated, (4) the activation or manipulation to be made, and (5) the indication of response adequacy or feedback. Task analysis should, therefore, address itself to each portion of the task. Task components 1, 2, 3, and 5 focus on the hardware on which the task is accomplished while component 4 focuses on the actual behavioral sequence of the task. Although detailed analyses of the hardware is necessary, it is important that behavior be central to the task analysis with other components in a supportive role if the task analysis is to provide output in a form that will be usable in the design of a training program of instruction.

> To be most effective, the task analysis should yield specific training objectives expressed in the form of observable actions to be performed, such as 'compute percentages' or 'set dials to required pressure and temperature.' Through task analysis, it should be possible to identify any activities requiring little training because they are already in the learner's behavior repertory. Similarly, task analysis should indicate which activities require the most intensive training because of intrinsic difficulty, importance for the job, or both (Anastasi, 1979, p. 105).

Anastasi's description of task analysis output is very general and applies to the entire range of curriculum development. Miller (1971a) characterizes this range as four non-independent areas of training design conceptualization that require information from task analyses. They are: (1) human factors engineering decisions; (2) selection decisions; (3) training decisions and (4) systems characteristics decisions. The goal of this paper although tangential to all the above, is more narrow. As was previously stated, our goal is to provide a framework for the determination of the minimum required fidelity of a simulator. Fidelity determination requires a more detailed and systematic output from task analysis than Anastasi's description of observable actions. All of the varieties of information which Anastasi mentions are important, but they are not enough. As Goldstein (1974) states, task analysis is only one portion of the assessment phase of curriculum development. It is during this phase that the task is analyzed, but other aspects of the training system, such as the organizational goals, the trainee characteristics, and the training delivery system are also analyzed during this phase. A thorough task analysis consists of both a descriptive and a detailed specification portion. In training literature, this distinction has been referred to as the difference between task description and task analysis (Miller, 1962; McCormick, 1976).

The use of the terms task description and task analysis can be confusing. Which of the two is necessary as input to the determination of training simulator fidelity? While there is variation in exactly how different individuals distinguish between these two forms, it is probably most beneficial to look at the difference as one of degree of detail. Task description specifies terminal (end-of-course) behaviors in general terms. An example of a task description might be "adjusts pressure gauge to appropriate pressure." On the other hand, task analysis systematically details the behavioral steps necessary to complete the task. It addresses itself to all of the components which Miller (1962) includes as part of each task, and indicates exactly what behaviors must be accomplished using each component. Thus a task analysis of the same task described above would indicate each display, each control, each required action as well as all information necessary for an individual to adjust the pressure gauge. In practice, the distinction between task description and task analysis may be defined differently or may not be made at all (several different approaches to this distinction may be found in Farina, 1969; Miller, 1962; Goldstein, 1974; and McCormick, 197). The important point is not how we label the type of analysis, but that we obtain the necessary information to make informed decisions about the requirements of the training device. Both forms are important for the determination of fidelity requirements. Description is important to yield the "observable actions" referred to by Anastasi in the establishment of training objectives. Detailed systematic analysis is also important to provide the information necessary to determine the configuration of the training simulator relative to the actual equipment used in the task (i.e., the simulator's fidelity). With this in mind, for the remainder of this paper, the combination of task analysis and task description as a single activity during phase I of the ISD process, will be referred to as task analysis. Let us now turn to a description of various approaches to task analysis. Different types of task analyses have been developed to serve different functions. Our purpose will be to determine which approach or combination of approaches will yield the type of information necessary for making decisions concerning the minimum required fidelity for training simulators.

Types of Task Analysis

There have been numerous approaches to the analysis of tasks. Several researchers have attempted to classify these approaches. One of the most widely used classifications of types of task analyses divides them into four conceptual bases (Wheaton, 1968; Fleishman, 1975; Fleishman, 1977):

- The Behavior Description Approach
- The Behavior Requirements Approaches
- The Abilities Requirements Approach
- The Task Characteristics Approach

The (1) behavior description approach (McCormick, Jeanneret & Mecham, 1972) is based upon observations and descriptions of what people actually do while performing a task. It provides an observer's view of the actions of a task performer. An example of a behavior description might be "pulls lever until pressure warning light goes out." The (2) behavior requirements approach (Gagne, 1962; Miller, 1962; Annette & Duncan, 1967), emphasizes the cataloging of behaviors which are assumed to be required in order to achieve criterion levels of performance. This approach would, for example, detail how quickly, with how much force, and for what duration the above level would have to be pulled in order to adjust the pressure to its desired level. The (3) abilities requirements approach (Fleishman 1977; Guilford, 1967; Theolgus & Fleishman, 1971), describes, contrasts, and compares tasks in terms of the abilities that are conceived as being relatively enduring attributes of the individual performing the task. The assumption is that different tasks require different abilities. In our lever pulling example, this approach would focus on the motor skills and the perceptual requirements necessary for individuals to accomplish the lever adjustment. Finally in the (4) task characteristics approach (Fleishman, 1972; Farina & Wheaton, 1971; Hackman, 1970) task description is predicated upon a definition that treats the task as a set of conditions which elicit performance. The assumption is that tasks may be described and differentiated in terms of intrinsic objective properties which they may possess. The components of a task (an explicit goal, procedures, input stimuli, responses and stimulus-response relationships) are treated as categories within which to devise task characteristics or descriptions. Besides the four discussed above, two additional conceptual bases have been described.

- The Phenomenological Approach

- The Information-Theoretic Approach

The (5) phenomenological approach (Klein, 1977) focuses on the way the task is experienced. It seeks to provide a holistic understanding of the system in which the task is embedded. In the (6) information-theoretic approach (Levine, 1971), the task is conceived as a transfer of information between components of the system (man-machine, machine-man, man-man, or machine-machine). Tasks are categorized based upon the constraints on information flow between components.

These six approaches to task analysis are alternative ways of viewing the process of task analysis. Each has a different goal and produces a different form of output. The distinctions between the approaches are important because by choosing one approach over the others, we are likely to obtain different results. These various results are due to the different criteria each approach applies to the analysis of the task. In 1969 Farina made a statement which is probably still true today. He stated that there are no deliberate eclectics in the field of behavior description. Each researcher seems to have his/her own purpose and chooses the approach which fits the purpose most closely. Farina also makes the important point that performance is a function of the task, the characteristics of the operator, and the characteristics of the environment (P = f(T,O,E)). While behavioral descriptors focus on the O portion of the equation, it is also necessary to obtain descriptors for the T and E portions. Table 2 lists these six approaches and indicates to which portion of the above equation they most closely apply. As can be seen from the table, each type of task analysis,

TABLE 2

Six Approaches to Task Analysis And Their Main Areas of Concern

	Approach	Main Area of Concern
1.	Behavior Description Approach	Operator
2.	Behavior Requirements Approach	Task
3.	Abilities Requirements Approach	Operator
4.	Task Characteristics Approach	Task
5.	Phenomenological Approach	Operator
6.	Information-Theoretic Approach	Task/Environment

while not necessarily ignoring all other areas, does have a central area of concern. The determination of training simulator fidelity cuts across all of these areas. Therefore, while complete eclecticism is probably not wise, it would be to out advantage to take those portions of each approach that provide useful information for the determination of simulator fidelity requirements and include them in our task analyses. Thus the information requirements for device design can be used to determine which approach(es) to task analysis should be used. Before discussing the content of these information requirements there is another issue of importance,: the way task analyses are utilized.

Honeywell (1978) conducted a survey of the Instructional System Design (ISD) process (TRADOC, 1975) task analysis procedure and 29 other methods of task analysis. The survey led to five conclusions: (1) Task analysis is an iterative process which continues during the entire length of the ISD process. That is, many individuals modify/interpret the task analysis during subsequent ISD phases. (2) There is much confusion in terminology usage, which makes it difficult to compare alternative models. (3) Most of the differences between models is in the level of detail of the analysis. (4) The ISD method is as reasonable as any other task analysis method. (5) The extent of impact of the task analysis on the device design is questionable. In other words, task analysis information often is overpowered by expert opinion, cost factors, engineering decisions, or other factors determining final training device configuration.

At least two important conclusions can be drawn from the above discussion. First there is no one task analysis method that is uniquely superior to other methods. We should, therefore, choose whatever procedures yield the information necessary to determine training simulator fidelity requirements.

It is not advantageous at the present time to limit ourselves to any one approach to task analysis. An eclectic approach will be beneficial as long as we are guided by the necessity of developing useful information. Secondly, we must be careful that the output, from whatever form of task analysis we use, is incorporated into the actual design of the training simulator. This goal may be accomplished most easily if the information we provide is perceived as useful by the designers of the training simulator. With these two interrelated goals in mind, we can turn our discussion to the actual information available from task analysis and then compare that information to the necessary information for determining training simulator requirements. In the next section we discuss the type of information that is provided by task analysis for the development of any training device and the information that is especially important for the development of training simulators.

Task Analysis Output

No matter what form of task analysis one chooses, if the intention is to design a training device there is certain minimal information that must be provided (Smode, 1971; Cream, Eggemeir, & Klein, 1978). Table 3 lists the important output information that could be obtained from a thorough task analysis.

If all of the information in Table 3 is not available from a single method of task analysis other methods should be employed until the information is obtained. For example, the behavior description approach would provide information based on observations of the behaviors of individuals performing the task. As such, it would not necessarily address the skills necessary to perform these behaviors (#5 in Table 3). To obtain this information we would need to rely on the behavior requirements approach. Neither of these approaches addresses background documentation (#1 in Table 3). In order to obtain information about the whole instructional system, including relevant documents, one would have to rely on the phenomenological approach. As this example illustrates, it is essential that we be guided by our required informational input for subsequent training simulator fidelity specification rather than by loyalties to any one type of task analysis.

Once the necessary information has been obtained from the task analysis, it may be used as input to the subsequent stages of the ISD process. Table 4 presents another version of ISD (Mechner, 1981) which shows that the task analysis information (Step #4) is next used to specify the instructional materials (Step #7). It is at this stage, (Step #7), assuming conditions warrant the use of a training simulator, that we must specify the configuration (i.e., the fidelity) of the training simulator. The task analysis provided specifications of the task performance under real field conditions. Step #7 specifies the behaviors and performance measures that will be called for in the training and testing setting. The instructional materials to train these behaviors and the method of measuring performance of these behaviors are, in essence, the hardware and software specifications

TABLE 3

Output Information From A Thorough Task Analysis

1.	Background Documentation
	-technical orders
	-regulations
	-manual
	-course syllabi
2.	Listing of all task and sub-tasks and their sequencing, including for each task:
	-initiating and terminating conditions
	-actions required
	-relevant controls and displays
	-standards of correct performance
3.	Equipment required for the task(s) including S-R conditions for each:
	-control
	-display
	-component (internal elements tested or repaired in maintenance tasks)
4.	Parameters affecting S-R descriptions
	-external constraints
	-relevant contingencies
	-malfunctions
	-performance parameters
5.	Skills and Knowledges required for the task(s)
6.	Characteristics of the trainee(s) who will perform the task.

TABLE 4

Outline of a 20 Step ISD Process (Mechner, 1981)

1. Project analysis - Preliminary studies and analyses; proposal.
2. Project manual - To be updated and maintained throughout project.
3. Gross task analysis - Job analysis or analysis of duties.
4. Task analysis - Development of job performance specifications.
5. Performance evaluation procedures - Development of evaluation items.
6. Validation of performance evaluation items - Target population test.
7. Behavioral analysis - Specification of instructional materials.
8. Production of examples and cases - Scripts, episodes, etc.
9. Final review of prerequisites - Additional pre-requ's are included.
10. Final specification of media - Specified on an item-by-item basis.
11. Performance system plan - Specification of sequences, types of activities to be used, check points, management plan, evaluation methods to be used, equipment, logistics, etc.
12. Physical specification of the system - Amount of each type of material such as pages, tapes, booklets, etc.
13. Development of first complete useable version of the system.
14. Test of first version - on a small group of target population members.
15. Analysis of data from the first test - Results are used to diagnose problems in the first version.
16. Development of second version of the complete system.
17. Test of second version - on another small group of target population.
18. Analysis of data from the second test - To diagnose remaining problems.
19. Production of the final version of the system.
20. Large-scale installation and implementation.

for the training simulator. One way to view the hardware specifications of a training simulator is as an assessment of its similarity to the actual equipment, since any aspect of the device must affect its similarity to the actual equipment. It is therefore both possible and useful to refer to the determination of a training simulator's specifications as a fidelity analysis. Let us now turn to a more detailed discussion of fidelity analysis to determine how best to use task analysis information.

FIDELITY ANALYSIS

In any training system it is necessary to determine how the training will be delivered. When it is determined that a training simulator will be used, the specifications for the degree of simulator fidelity can be used as guidelines for constructing the simulator. Determining the requirments for fidelity is based upon the inputs provided by the task analysis. A fidelity analysis should take this information and determine the necessary physical and functional characteristics of the training simulator in order to provide the most cost effective training. In order to ensure that the physical and functional characteristics of the training simulator provide the most effective training, the fidelity analysis should be based on the best empirical data available on the relationships between training simulator configurations and training effectiveness. Unfortunately, as was mentioned above, there exists very little empirical data on these relationships. In the following sections various factors are discussed that interact with degree of fidelity to produce effective training. A preliminary format for organizing future research is presented which seeks to provide the necessary empirical data to serve as guidance in making training simulator fidelity decisions. We first turn to a discussion of how humans function in systems. This discussion should make us aware of some of the factors which must be considered when we seek to determine the characteristics of a simulator designed to train a human to function in a given system.

Human Functions in Systems

Since any simulator is designed to train individuals to function in some real world system, we shall begin our discussion with a brief overview of how humans function in such systems. Gagne (1962) states that a human behaves in a system "as a data transmission and processing link inserted between the displays and controls of a machine" (Gagne, 1962, p. 37). As such, each human function may be described as a kind of input-output transformation or as a transformation performed on inputs to produce outputs (Gagne 1962, p. 53). In this context there are basically three types of human functions: (1) sensing, which indicates the presence or absence of a difference in physical energies, (2) identifying, where the operator makes a number of different responses to a number of different classes of stimulation, and (3) interpreting, which consists of identifying the meaning of inputs and making outputs based upon those meanings. The description of one or more of these three functions can provide a basic definition of the task which any simulator is designed to train. To provide useful guidance, these descriptions should elaborate on the functions by detailing the necessary inputs (stimuli) and the required outputs (responses) for each activity.

Detailing inputs is relatively straightforward. Displays and/or other informational cues (audio, etc.) should be listed and related to the sequence of activities requiring them as well as to any other displays or controls necessary to the activity. The detailing of outputs is more difficult as they may vary much more than do inputs. Outputs or responses have been categorized as three types (Gagne, 1962): (1) Unitary responses are required actions (like pushing a switch) which are performed in a relatively brief amount of time without change in direction during its occurrence. (2) Autonomous sequences, require continuous, uninterrupted movement, (like turning a crank) and appear to be relatively self-contained and internally controlled. (3) Flexible sequence (like tracking an irregularly moving target) are guided and modified by input signals from displays and other parts of the operator's environment. The description of each of these types of responses requires elaboration of a different degree of detail. The unitary response only involves a single or limited number of controls. The autonomous sequence and the flexible sequence may require a large number of controls and possibly additional displays as well. To determine the necessary fidelity for a simulator to train these responses, we therefore need to know all of the related controls and displays necessary to accomplish the response. All of this information should be available from a task analysis that is well designed and implemented.

There have been several attempts to relate tasks to the actual physical proficiency or perceptual motor skills required for their performance (Fleishman, 1972; Fleishman, 1975; Farina & Wheaton, 1971). This approach has not proven very successful, but further efforts which relate these skills to the critical aspects of both the actual equipment and the training simulator are necessary if this approach is to be useful in providing guidance in specifying the configuration of training simulators. The next section discusses the components which must be considered in the determination of this simulator configuration or, in other words, the level of fidelity of the training simulator.

Equipment Components Considered in Fidelity Analyses

As should be clear from our discussion of human function in systems, controls and displays are critical components which must be represented in any simulator. If the human is to act as an input-output transformer, the vehicles for the inputs (displays) and for the outputs (controls) must be present. It is the responsibility of the fidelity analyst to determine how realistic the controls and displays should be on the simulator as well as the layout of the controls and displays. For some tasks, such as maintenance training, we must also consider the simulator fidelity of internal components of the equipment. Which internal components should be represented in the simulator and the minimum fidelity required to effectively train an individual to work with these internal components are questions that must be addressed in the design of maintenance training simulators. Another area that must be addressed in maintenance training is the inclusion of test equipment. Should the test equipment be simulated with a separate device or should it be incorporated into the simulator itself? What are the physical and functional requirements for the controls and displays of the test equipment? For each component of the actual equipment and the test equipment associated with it, a decision must be made about how it will be represented in the simulator(s). Table 5 shows some of the factors which should be considered in a fidelity analysis. Depending on the task to be trained, all or some combination of these factors will have to be considered to determine the fidelity of the training simulator.

To make informed decisions about the design of the training simulator, the best data available on the relationship between its configuration (fidelity) and its training effectiveness should be consulted. As was stated above, there is a conspicuous lack of data on this relationship and decisions are often based upon expert opinions or cost factors. The next section provides an organizing format for further research to provide the necessary data for use in making such fidelity decisions. It does this by comparing those factors shown in Table 5 with the information available from task analyses.

Fidelity Research: An Organizing Format

There are a variety of worksheets that have been developed for task analysis (Miller, 1962; Synder, 1960; Farina & Wheaton, 1971; McCormick, 1974; McCormick, 1976; TRADOC, 1979). Most of the information necessary for a fidelity analysis can be found on these worksheets. As has been discussed previously, research is necessary to determine empirically the training effects of the parameters covered in a task analysis. The task analysis worksheet that is currently used in the development of curricula at Army training schools (TRADOC, 1979) will serve as the model in the following discussion (some changes in wording will be used to clarify concepts). Table 6 lists the information provided on this task analysis worksheet. This information can differ depending on which of the previously discussed task analysis approaches is used by the task analyst. Also, though all of the aspects of a task (according to Miller's definition above) are addressed, there is no way, from this list, to tell how adequately each aspect is covered. As mentioned above, a task analysis can be used in many areas of instructional system development. It can be used in media selection, development of instructional strategies, institutional selection, trainee selection, and many other areas besides making decisions concerning fidelity requirements for training simulators. What is necessary to make fidelity decisions is for the fidelity analyst to focus on the information required for these fidelity decisions (Table 5). This information may be available from the standard task analysis worksheet (Table 6) but may be difficult to extract from the worksheet in its standard format. A reorganization of this information is needed to support decisions concerning fidelity requirements. In order to accomplish this reorganization, a format like the following (Table 7) may be used (any format which affords easy access to the relevant information will suffice). It is organized

Table 5

Some Factors to be Considered in a Fidelity Analysis

1. Controls
2. Displays
3. Layout
4. Actions Required
    a. Perceptual/Motor Skills
    b. Physical Proficiencies
    c. Abilities
    d. Performance Criteria
5. Internal Components & Layout
6. Test Equipment
    a. Controls
    b. Displays
    c. Layout
7. Cognitive Skills Required

TABLE 6

Information Obtainable From a Job and Task Analysis Worksheet

(Source: TRADOC, 1979)

1. Task Data (title, type, other administrative information)
2. Task Usage (active, reserve, mobilization)
3. Type Analysis (new, revision)
4. Administrative Data
5. Survey Data/Field Feedback (Subject Matter Expert Comments)
6. References (used in analysis, required for task)
7. Job Aid Recommendation (yes, no)
8. Hazard Potential (training, on job)
9. Safety Certification Requirements
10. Current Training Materials
11. Instructional Site Recommendation
12. Equipment Used with/to Perform Task
13. Enabling Skills and Knowledges Required (function or specific) for Task
14. Detailed Task Information (% performing, lag time, frequency, time spent performing, consequences of inadequate performance, probability of inadequate performance, delay tolerance, difficulty, etc.)
15. Miscellaneous Data/Comments
16. Performance Elements/Steps
17. Cues
18. Conditions
19. Standards
20. Skills/Knowledges (to be taught)
21. Job Performance Measurement Data

Table 7

Sample Format for a Fidelity Analysis Worksheet

TASK NAME______________________ TASK STEP/ELEMENT______________________

DISPLAYS_*_ ___ ___ ___ CONTROLS_*_ ___ ___ ___

INTERNAL COMPONENTS_*_ ___ ___

CRITICALITY RATING_____ DIFFICULTLY RATING____ FREQUENCY RATING_____

TEST EQUIPMENT REQUIRED? YES___ NO___

TEST EQUIPMENT DISPLAYS_*__ TEST EQUIPMENT CONTROLS_*__

ACTIONS REQUIRED____

CONDITIONS AND STANDARDS FOR ACCOMPLISHING STEP/ELEMENT______________________

MEASURES OF TRAINING EFFECTIVENESS______________________________

SKILLS/KNOWLEDGES REQUIRED
PERCEPTUAL/MOTOR FACTORS_**_ ___ __
PHYSICAL PROFICIENCY FACTORS_***_ ___ ___
COGNITIVE SKILLS ______________________________________

TRAINEE LEVEL______________________ AUGMENTED FEEDBACK REQUIRED? YES___ NO___

OTHER TRAINING FEATURES(E.G., ADAPTIVE DIFFICULTY, ETC)______________________
____

RELATIONSHIP TO OTHER TASK ELEMENTS:
REQUIRED FOR OTHER ELEMENT? YES___NO___ WHICH ELEMENT(S)?______________________
INDEPENDENT OF OTHER ELEMENTS? YES___ NO___ RELATED ELEMENTS______________________
MUST BE DONE IN SEQUENCE WITH OTHER ELEMENTS? YES___ NO___

OTHER INFORMATION:

*enter number which refers to detailed line drawing or photograph of actual equipment showing location.

**enter the number of the perceptual/motor factor--1 to 11 (Fleishman, 1975)

***enter the number of the physical proficiency factor-- 1 to 9 (Fleishman, 1975) by task elements in sequential order with a separate page or section for each task element. Each activity in a task element is fully described. All displays and controls (including those on test equipment) are indicated either on detailed line drawings or on photographs of the actual equipment. This information is important when determining if the layout of controls and displays is an important factor for this particular task element. Some components will not have to be represented in the simulator because they are not involved in the task. On the other hand, some components that are not directly involved in the task activities may need to be included because they help locate components which are involved in the task. This reorganization helps the fidelity analyst translate the task analysis information into a "language" that is more adequate for fidelity decisions. It may also show that it is necessary to involve the fidelity analyst earlier in the process to insure that the task analysis emphasizes areas which affect fidelity decisions.

It should not be assumed that all the fidelity answers can be found in task analysis data. The task analysis may only tell us the broad outline of the task as it is accomplished in actual field conditions. It does not tell us how to effectively train people for that task. Here is where our reorganization of task analytic data may help us to determine where further research efforts are needed. We can see that many variables are covered in Table 7. Each of these variables requires empirical data on its effect on the relationship between training simulator fidelity and training effectiveness. However, if our research efforts are to be productive, they must be timely as well as relevant. We should direct our attention to areas which have the highest payoffs but which have not been researched. For example, in the area of operations training Martin & Waag (1978) determined that very high fidelity in flight simulators was detrimental to training effectiveness when the trainee's level of experience was low. At this stage, our research efforts might therefore be directed more profitably to other questions besides the effect of trainee level in an operations task. We might rather choose to conduct our research on this effect in maintenance tasks or as it is modified by other parameters such as training context. The research studies in the development of such a fidelity data base should begin by narrowly demarcating variables to determine how they interact with fidelity levels. Figure 2 shows a sample table from such a narrowly demarcated study. In this example, a maintenance task is contrasted with an operations task to determine the "best" mixture of physical and functional device characteristics for each respective task type. Continuing repetition of the above sequence (always beginning with Table 7 or its equivalent) can result in the development of an iterative data base which will contain empirical answers to fidelity questions. As later research efforts add empirical data to our iterative data base, more complex designs will be needed. For example, the study described above would be repeated for various levels of trainees and for various training contexts. Each study would add more data to the data base. The key to a systematic data development effort, however, is to return constantly to our fidelity analysis format (or one like it) to determine where the next research thrust should be directed. Once all variables have been investigated, the studies may be replicated to develop more reliable and valid data.

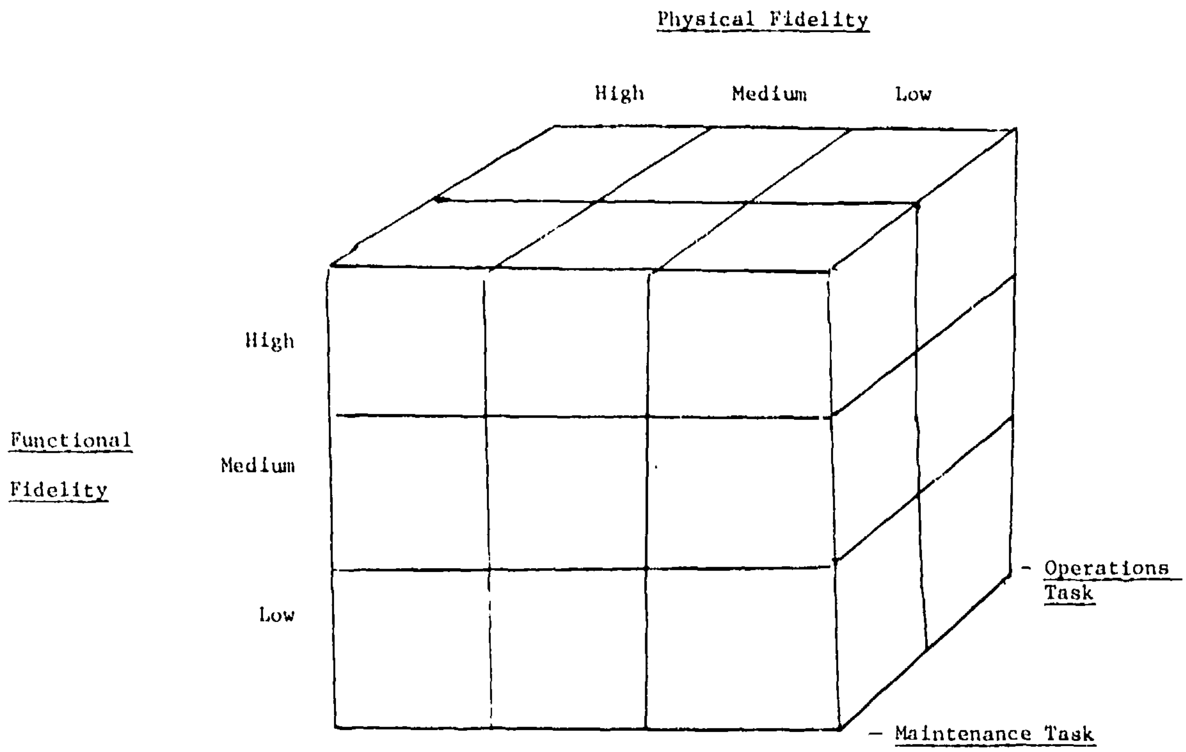

Figure 2. Sample Table for a Preliminary Fidelity Study Comparing a Maintenance and an Operations Tasks

By using such a systematic approach to organizing fidelity research, we not only address the important issues but we reduce duplication of effort and ultimately produce a useful fidelity data base. In addition, a standard fidelity analysis format provides a framework for curriculum developers to organize and use the results of our research.

The proposed simulator fidelity data base should contain data on all of the variables which interact with simulator fidelity to produce a given amount of training effectiveness. Table 8 lists the variables which interact with fidelity. Each of these variables as well as their combinations must eventually be included in the iterative simulator fidelity data base.

Degrading Simulator Fidelity: An Additional Issue

Training simulators almost always degrade the fidelity of components which are not essential to the specific task to be trained. However, there are other reasons for departures from perfect fidelity. According to the above definition of training simulator fidelity, it is a measurement of similarity between the training simulator and the actual equipment which is simulated. Any change away from the configuration of the actual equipment is therefore a degradation in fidelity. Thus, the fidelity of a simulator may also be reduced by adding features that are not found on the actual equipment, such as augmented feedback displays. The point is that reduced simulator fidelity may arise from additions to as well as subtractions from actual equipment features. Fidelity research must also empirically determine the relative effects of these two types of fidelity degradation. It is suggested that the addition of features to a simulator be called additive fidelity degradation and the removal of features (relative to the actual equipment) be called subtractive fidelity degradation and that the relative effects of each on training effectiveness be included in the iterative simulator fidelity data base.

SUMMARY AND RECOMMENDATIONS

Many factors which affect the relationship between simulator fidelity and training effectiveness have been discussed. The following major points were made:

1. Simulator fidelity analysis is the process of specifying the characteristics to be incorporated into a training simulator. Fidelity may be degraded by adding features to the simulator that are not found on the actual equipment as well as by subtracting features from the simulator.

2. Task analysis is the first step in the development of an instructional system. If training is to occur we must know what it is we are going to train.

Table 8

Variables Which Interact With Fidelity

1. Task Type - Operations - Maintenance - Others	5. Stage of Training - Introduction - Procedural Training - Familiarization Training - Skill Training - Transition Training
2. Task Difficulty	6. Training Context - Institutional - Field
3. Specific Skills Required By Task - Motor - Perceptual - Cognitive - Others	7. Incorporation of Device into POI
4. Trainee Sophistication - Novice - Intermediate - Expert	8. User Acceptance - Instructors - Students
	9. Use of Instructional Features

3. Various types of task analysis exist which differ in their conceptual orientations or methods. We should not limit ourselves to any one type of task analysis, rather we should use any methods which yield the necessary information for making instructional system design decisions (including the configuration of training simulators).

4. The output from the task analysis becomes the input for the fidelity analysis. A sample format for fidelity analyses was provided.

5. It is important to distinguish the type of training to be provided by the training simulator. For example, maintenance and operations training may differ completely in their realm of focus. On the other hand, many of the same skills and knowledges must be trained for both areas. We need to elaborate on the similarities and differences between the training needed on different types of tasks.

6. Variables which interact with fidelity to affect training effectiveness were discussed. It is important that each variable be empirically examined. An organizational format was proposed to guide empirical research and also to organize data that have already been obtained. At least the following variables require empirical investigation to determine the most appropriate fidelity levels for effective training:

a. Task Type

b. Task Difficulty

c. Training various skills:

- Motor Skills (i.e., unitary responses, autonomous sequences, flexible sequences)

- Perceptual Skills (i.e., sensing, identifying, interpreting)

- Cognitive Skills (i.e., troubleshooting)

d. Trainee Sophistication

e. Stage of Training

f. Various Training Contexts

h. Effects of additive versus subtractive fidelity degradation

i. Effects of Instructional Features

7. Data from empirical and analytic studies on fidelity should be accumulated into an iterative data base which can serve as guidance for making decisions about the configuration of training simulators.

It is recommended that research efforts begin with simple questions such as what are the appropriate fidelity levels for a single type of perceptual/motor task. Only when data have been obtained from the simple designs should more complex designs be studied. However, no matter which variables are investigated or how complex the research design, it is vital that the empirical data be accumulated in a systematic manner. The development of an iterative training simulator fidelity data base will ultimately afford the guidance necessary to make decisions to specify the physical and functional characteristics of a training simulator as well as determining the training context which can best utilize the simulator to provide the most effective training.

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