INTEGRATING TRAINING AND FIDELITY REQUIREMENTS IN SIMULATION SYSTEM DESIGN

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ABSTRACT

Fidelity analysis is the means by which training requirements are translated to hardware requirements for training device design and acquisition. However, there are few rigorous, analytical approaches to this important analysis step. Current practice is dominated by the engineering approach, which focuses on maximizing technology content based on the subjective inputs of subject matter experts.

This paper describes a structured methodology for linking training requirements developed through the ISD process with fidelity requirements in order to optimize hardware design for simulation systems. While new, it has proven its utility in applications to two aircraft mission crew simulators and is currently being applied in development of the Naval Aviation Simulation Master Plan. Lessons learned in these applications will be discussed.

BIOGRAPHIES

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Senior Staff Engineer

Mr. Hemenway is currently a Senior Staff Engineer and Human System Integration Team Leader at Dynamics Research Corporation. He conducts and manages a wide range of Human System Integration and requirements analyses for US Navy, Air Force and Army weapon systems. His most recent projects include training system requirements and fidelity analyses of a weapon system trainer for the E-6B aircraft, a training system alternatives analysis for the AC-130U, and supportability assessments for an upgrade of the Army UH60 helicopter. He is currently technical lead for training system requirements and fidelity analyses for the Naval Aviation Simulation Management Plan (NASMP) Training Systems Requirements Analysis (TSRA).

Mr Hemenway has over 20 years experience in military training and logistics systems and holds a Bachelor of Science Degree from the US Military Academy and served as a combat engineer troop leader and maintenance officer. He has been conducting ISD, training, manpower and human factors engineering studies of military training systems for over 15 years. He is a Professional Engineer (PE), a Certified Professional Logistician (CPL), and has earned certifications as a Quality Engineer and Reliability Engineer.

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Dr. Dennis Duke is currently working as a senior Instructional Systems Specialist at the Naval Air Warfare Center Training Systems Division (NAWCTSD) located in Orlando, Florida. In this position he acts as the senior consultant who leads various interdisciplinary engineering teams in the analyses of different types of organizations from a training perspective. The analyses that are performed result in the design and development of total training systems that satisfy the activity's training requirement(s) in the most effective and efficient manner possible.

Dr. Duke, a native of Pittsburgh, Pennsylvania, received a BA in Education and a BS in Communication Systems from Penn State University. He also earned a MA in Communication Systems Design from Ohio University and a MBA in Government Contract and Acquisition Management from the Florida Institute of Technology. His doctorate is in Administration from the University of Central Florida. Dr. Duke has over 25 years of experience in the analysis, design, development, implementation and evaluation of training systems within the Department of Defense and other federal agencies.

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INTRODUCTION

The Instructional System Development (ISD) process should provide a continuous, integrated, analytical path leading from training analysis to training system design. Two major products, developed as a result of the ISD process, define what needs to be trained (Training Situation and Task Analysis) and how it should be trained (Media Selection and Training System Alternative Assessment). The results of the ISD analysis must then be translated into training system acquisition requirements in order to complete the training systems development cycle. The process of converting training requirements into design specifications is fidelity analysis.

The goal of fidelity analysis is to define the level of realism that produces the desired level of training effectiveness in a cost-effective manner. According to Thorndike, learning transfer is a function of the similarity between the operational and training environments. (Hays, 1989) Subsequent research confirmed the general application of this theory, but went on to demonstrate an indirect relationship between training effectiveness and training realism. In other words, "training simulation does not require an exact representation of the real-world in order to provide effective training. It may, in fact, be necessary to depart from realism in order to provide the most effective training." (Hays, 1989) Given the cost of duplicating system function and presentation, this was an important advance in ISD theory.

Training fidelity is defined as the degree of similarity between the training situation and the operational situation. (Hays, 1989) The goal of training fidelity analysis is to maximize training effectiveness for specific training tasks, not necessarily to achieve 100% physical realism. Training fidelity is distinguished from engineering fidelity, which attempts to maximize the congruence between the simulation and physical reality. Training fidelity is also distinguished from simulation fidelity. The goal of simulation fidelity is achievement of a realistic representation of operational space in a virtual environment.

Training fidelity is not based directly on the operating characteristics of the equipment itself. It is based on, and flows from, the instructional requirements of the training task and the perceptual requirements of the trainee. (Hays, 1989) It follows that knowledge of instructional design is an essential qualification for the fidelity analyst. Although system design and engineering, job and task performance expertise provide important inputs, they are secondary to the primary task of fidelity analysis-training effectiveness.

Fidelity is a design characteristic of the training device. It may be hardware related, or software related, however, fidelity analysis focuses on the point of interaction between the human and the system. It poses the question, "How should the system behave relative to the human in order to maximize the training experience?" The operation or functioning of the actual equipment, as such, is a peripheral concern. Training transfer is rooted in the interface between the user and the system. How the training system reacts or appears visually, aurally, and tactilely is the primary concern of the training fidelity analyst. For example: a message on a video screen cues the user to take a specific action. Depending on the task in question, training fidelity analysis may be concerned with the accuracy of the content, the format, or the timing of the message. The actual source of the message, the frequency, the signal or the type of antenna, etc. is not relevant to the training function. In fact, the performance of actual equipment may be modified significantly in order to produce a desired learning experience or to allow instructor input and control of the training scenario.

This paper describes a task-based methodology for training fidelity analysis and its application in training system requirements development for the mission crew of an operational aircraft.

METHODOLOGY

As late as 1996, LCDR Talbot, RN wrote: "Fidelity in training is a subject in which there are currently few established rules." As currently practiced, fidelity analysis relies heavily on the subjective input of subject matter experts (SME). While subject mater experts are well qualified to describe how they operate or maintain equipment, they are less able to describe what is needed for effective training. The result is predictable- requirements for training devices that attempt to reproduce all aspects of the operating system.

The methodology presented here (see Figure 1) is an attempt to provide some measure of analytical rigor to the art of fidelity analysis by building a bridge between training needs and hardware requirements. This goal is achieved by focusing on the concrete elements of the task environment. Training tasks are reduced to a series of cues and responses. Cues and responses that involve interaction with hardware components are then linked with those components. Fidelity levels are assigned in nine dimensions and translated to qualitative specifications for major hardware components.

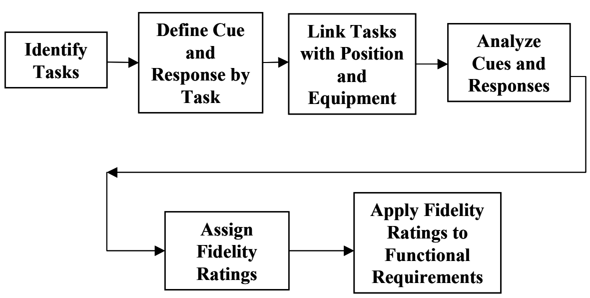

Figure 1. Training Fidelity Analysis Process

APPLICATION

A training systems alternative assessment for the E-6B aircraft provided a laboratory for application of this fidelity analysis methodology.

Task analysis is the first step in the fidelity analysis process. During this step, analysts worked with system documentation and with SMEs to identify and characterize system tasks.

Cues and responses for each task provided the analytical framework for describing the similarities between the training system and the operational environment. A cue signals the subject to begin executing the task. A response is the action or step resulting from the cue.

Cues and responses provide a concrete description of the human system interface and serve as the bridge we will use to walk from training to design requirements. "It is vital that the task analysis breaks the job down to a sufficient level so as to allow the cues and responses to be extracted from the data captured. These cues and responses then form the basis of the information which dictates the final fidelity level which needs to be applied to the subsequent training equipment." (Talbot, 1996)

Subject matter experts provided cue and response data in a three-day workshop. During this workshop, SMEs identified cues, and responses for each task and identified the equipment components and subsystems associated with each task. Fears that cues and responses for complex jobs would proliferate and become unmanageable proved unfounded. Workshop participants were directed to focus on a single event or behavior rather than a set of complex behaviors. For example, the response to a cue of "see smoke in the cabin" would be "operate fire extinguisher" or "sound verbal alarm". "Execute fire emergency procedures" was not an appropriate response. Worksheets (see Figure 2) were used to structure the process and document the results. Participants recognized the appropriate level of response very quickly and provided much useful data.

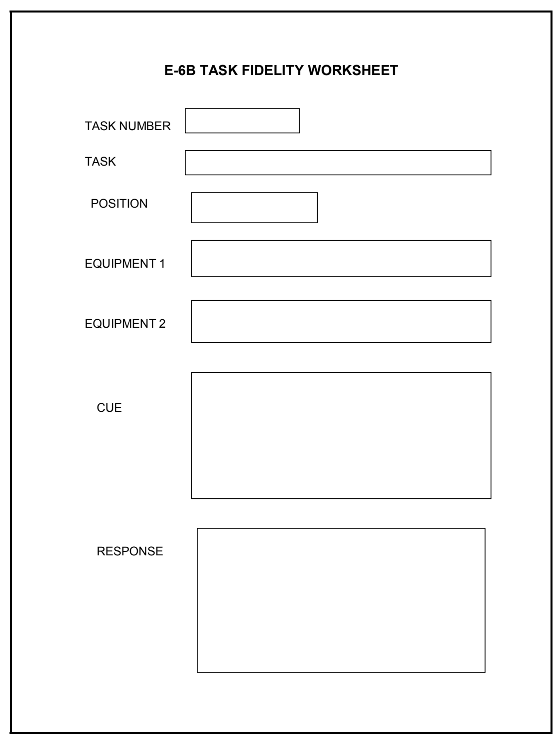

Figure 2. Sample Task Fidelity Analysis Worksheet

Analysts normalized the data collected in the workshop to facilitate the fidelity analysis. They decomposed cue and response data and allocated hardware components to the results. The Cue and Response to Equipment Allocation Worksheet (see Figure 3) supported this analysis step.

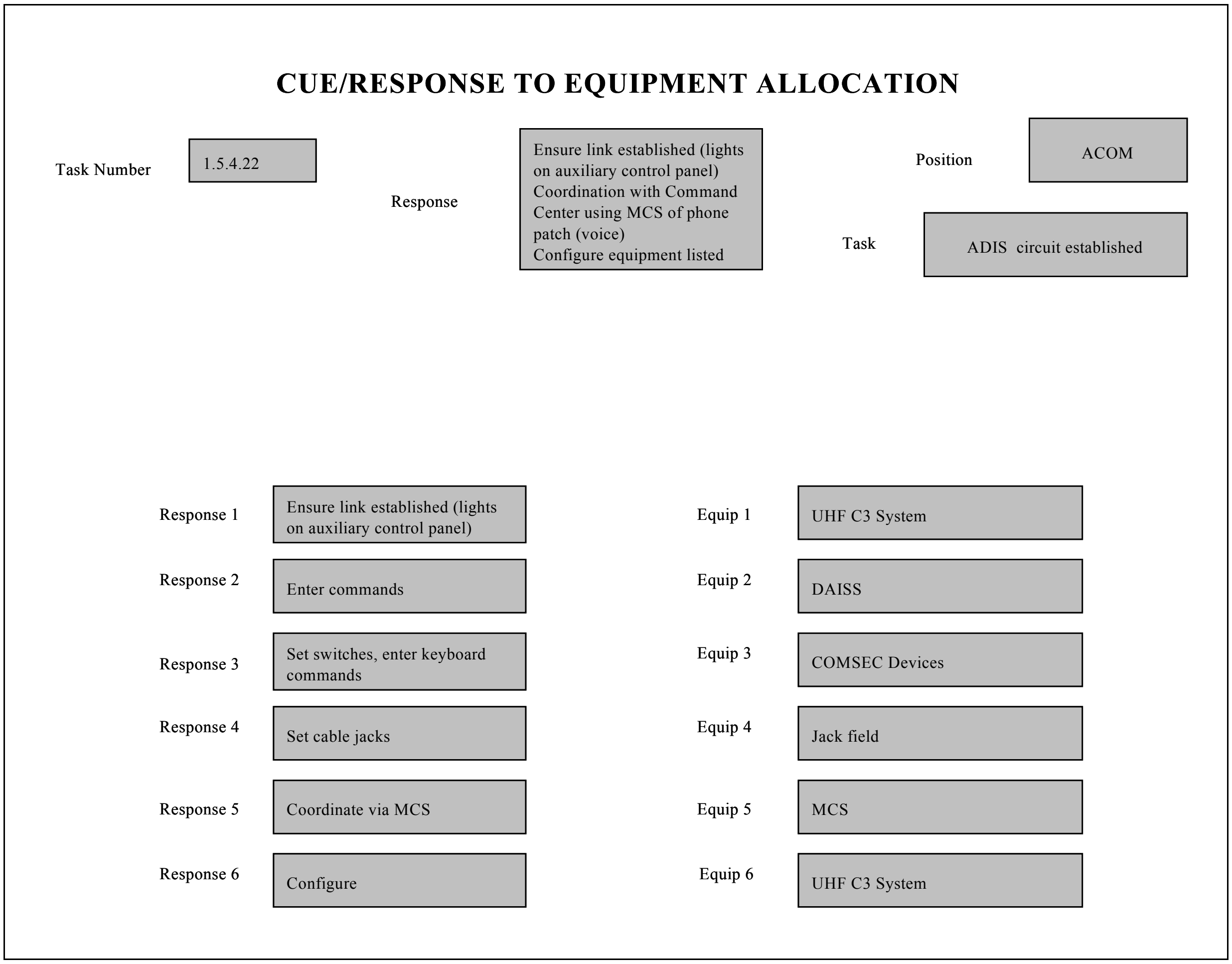

Figure 3. Cue and Response To Equipment Allocation Worksheet

Normalization of the data shifted the focus away from the task and the hardware component, and placed it squarely on the human machine interface. Analysts coded cues and responses (see Figure 4) using the taxonomy of Sensory Stimulus Cues, Table 30, MIL-HDBK-29612-2. This table classifies stimuli into visual, tactile, auditory, olfactory, and affective categories. Categories are further broken down into domain and type of sensory stimulus.

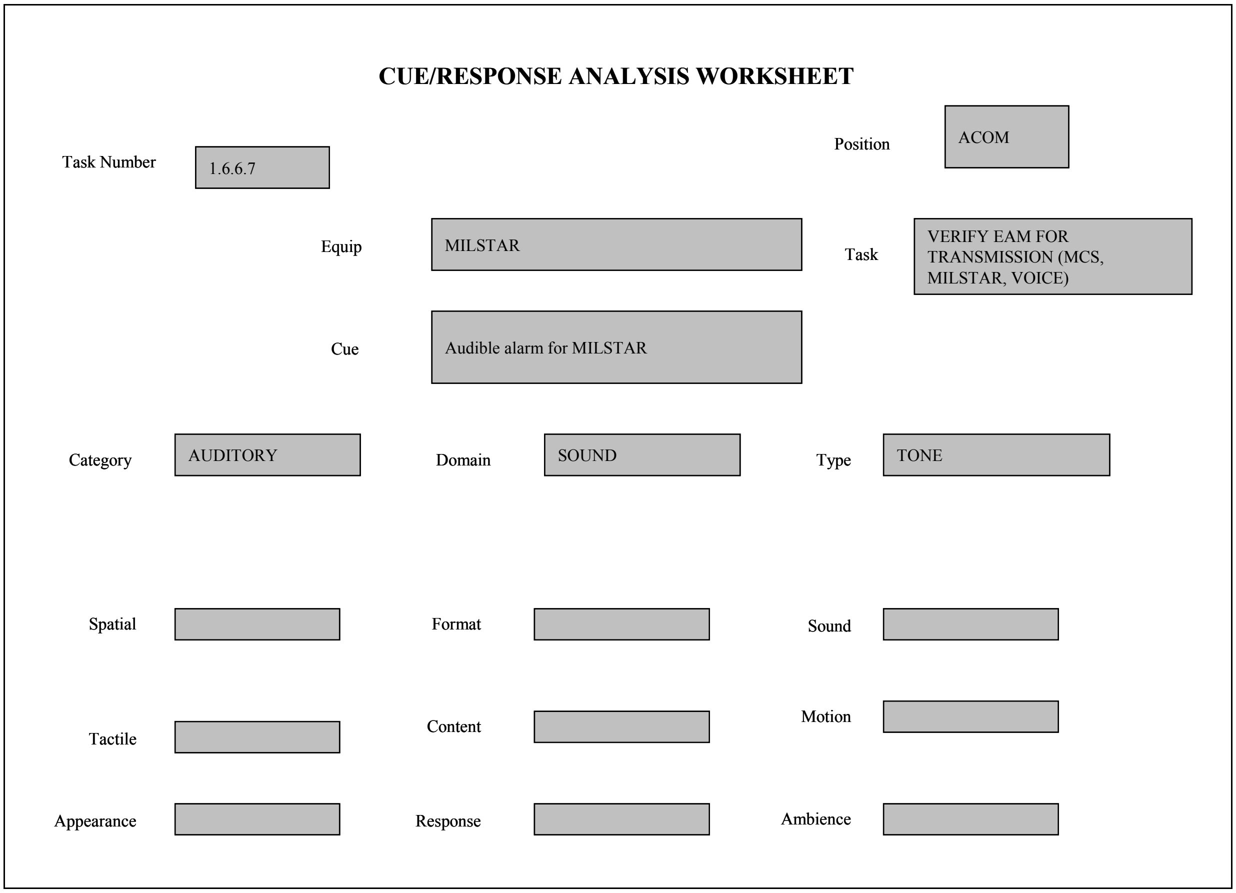

Figure 4 Cue and Response Analysis Worksheet

Fidelity is a multi-dimensional variable. The user interacts with a system component in several dimensions and on several levels. In order to achieve its goal of training effectiveness, fidelity analysis must capture all critical aspects of the human machine interface. For example, one component may be assigned several fidelity values based on the number and type of physical interface points (keyboard, screen, signal lights, controls, etc.) and cue and response characteristics.

Hays proposes a two dimensional model that defines fidelity in terms of: 1) physical characteristics of the hardware and hardware performance and 2) functional characteristics relating to the format and presentation of information. (Hays, 1989) Although valid, this model is not robust enough to provide the depth and breadth of detail needed for requirements definition for today's complex simulators and training devices. Talbot has built on this foundation to create a fidelity model in nine dimensions (Talbot, 1996) (see Figure 5).

FIDELITY TYPE	DIMENSION	DEFINITION
PHYSICAL	**Spatial**	How important is the degree of replication of the position and size of keys, buttons, switches, knobs, displays etc. to the *performance* of the task?
	Tactile	How important is the degree of replication of the feel and kinetics of the Human System Interface (HSI) to the *performance* of the task?
	Appearance	How important is the degree of replication of shape, color and luminescence of the system and its controls to the *performance* of the task?
FUNCTIONAL	**Format**	How important is the degree of replication of the format of the data displayed or the actions taken to the *performance* of the task?
	Content	How important is the accuracy of replication of information displayed or heard to the *performance* of the task? e.g., frequency, bearing, level, audio components, etc.
	Response	How important is the degree of replication in reflecting the data change rates and display response to the *performance* of the task?
ENVIRONMENTAL	**Sound**	How important is the degree of replication of background noise, conversation and sympathetic resonance to the *performance* of the task?
	Motion	How important is the degree of replication of incidental movement of the system, equipment or platform to the *performance* of the task?
	Ambience	How important is the degree of replication of the surrounding heat, light and humidity to the *performance* of the task?

Figure 5. Talbot's Fidelity Model

The Cue and Response Analysis Worksheet (Figure 4) was used to apply these definitions and assign fidelity levels to equipment. In the previous analysis step, equipment was linked with cues and responses. In this analysis step, fidelity levels (High, Medium or Low) are assigned to each equipment- cue and response pair based on the sensory analysis of the user machine interface. Fidelity levels were defined for each of the nine fidelity dimensions based on the definition and the level of user machine interface. General criteria were defined as follows:

- High Fidelity - Precise representation of the equipment is essential to training transfer. Physical and/or cognitive interactions with the hardware are an integral aspect of the cue and response. Accurate component appearance, and behavior, is essential to cue and response execution. (Value-3)
- Medium Fidelity - Some reduction in precision or tolerance of the physical representation is acceptable. The cue and response includes physical and/or cognitive interaction with the system, but that interaction is not integral to the cue or response. For example, data on a screen provides a cue to perform a task. This data is presented in a fixed format, but the cue is in the content of the data. (Value-2)
- Low Fidelity - Simulation of generalized and universal functions only. Precision of the physical representation has marginal training value. (Value-1)

When there is no requirement in a fidelity dimension, a value of "0" was assigned. For example, a cue calling for a warning buzzer has no spatial dimension.

In the final analysis step, the analysts, translated fidelity assessments to functional requirements. Descriptive fidelity requirements were assigned to each component or subsystem in each of the nine fidelity domains (see Figure 6).

A single component or subsystem is typically used in the execution of several tasks and involves several cues and responses. Therefore, we encountered several instances where multiple fidelity levels had been assigned to a single component. In these cases, a single fidelity value was assigned using the following rules:

- If all recommendations have been assigned one fidelity level, (high, medium or low), that level will be assigned to the component.
- If recommendations are predominantly for high fidelity, a high fidelity value will be assigned.

- If recommendations are mixed, i.e. not clearly high fidelity, tasks associated with the component will be assessed to determine if high fidelity is critical for some tasks.
- If recommendations are mixed and no critical tasks require high fidelity, a lower level of fidelity will be assigned.

FIDELITY RECOMMENDATIONS FOR THE ANTENNA CONTROL CONSOLE (ACC)

FIDELITY TYPE	FIDELITY DIMENSION	FIDELITY REQUIREMENT
PHYSICAL	**Spatial**	The size and position of knobs, switches, and buttons shall approximate that of the actual equipment. (Mid) The size and position of the keypad and display screen shall approximate that of the actual equipment. (Mid) The size and position of indicator lights shall approximate that of the actual equipment. (Mid) The size and position of the video screen shall approximate that of the actual equipment. (Mid)
	Tactile	The intensity and quality of the physical action of the keypad, buttons, knobs and switches shall be similar to that of the actual equipment. (Lo)
	Appearance	The color, shape, surface texture and layout of interfaces and controls shall approximate the actual equipment. (Mid) The color, intensity and quality of the screen display and video shall approximate that of the actual equipment (Mid). The color and quality of indicator lights shall approximate the actual equipment. (Mid)
FUNCTIONAL	**Format**	Keypad data entry and command; and switch sequences shall duplicate actual equipment. (Hi) Screen displays shall provide 100% replication of operational formats. (Hi) The clarity of video images shall be equal to the operational equipment. (Hi)
	Content	The precision of keypad entry and screen displays shall equal operational equipment. (Hi) Video content shall portray actual events accurately. (Hi)
	Response	The response time of all indicator lights, and screen displays to changes in operational parameters and keypad commands shall equal the operational equipment. (Hi)
ENVIRONMENTAL	**Sound**	Background noise is not a factor for the man-machine interface of this equipment.
	Motion	Platform movement is not a factor for the man-machine interface of this equipment.
	Ambience	Ambient environmental factors are not a factor for the man-machine interface of this equipment.

Figure 6. Sample Fidelity Recommendations

CONCLUSION

The methodology described here has been applied to training system requirements analyses for the E-6B and EP-3C aircraft. In both cases, it produced consistent, supportable and realistic recommendations. Because the data collection effort was focused and the data requirements were well defined, SMEs responded positively and enthusiastically to the demands of the workshop. Although, analysis of cues and responses and the assignment of fidelity levels represented a significant workload for the analyst, the approach was straight-forward, manageable, and repeatable.

We did find that planning is essential in order to focus the process on critical issues and to minimize the workload. Significant efficiencies are possible by grouping hardware components and job tasks. We also found that an accurate task list provides the foundation for this fidelity analysis methodology and is essential to its success.

To date, this methodology has been applied to hardware driven simulators where equipment operation tasks predominate. We propose that the methodology, particularly Talbot's model, is well suited for fidelity analysis of software driven systems in which cognitive tasks and decision-making tasks are most important.

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