DESIGNING TRAINING DEVICES: THE OPTIMIZATION OF SIMULATION-BASED TRAINING SYSTEMS*

Michael J. Singer, Ph.D.
Army Research Institute
Orlando Field Unit
Attn: PM TRADE/PERI-IF
Naval Training Systems Center
Orlando, FL 32813-7100

and

Paul J. Sticha, Ph.D.
Human Resources Research Organization
1100 South Washington St.
Alexandria, VA 22314

ABSTRACT

Effective training devices are those that meet training requirements at minimum cost, or provide the maximum training benefit for a given cost. The Optimization of Simulation-Based Training Systems (OSBATS) is a model that is designed to facilitate the investigation of tradeoffs involved in developing effective training device concepts. The model is based on benefit and cost approximations that are used to analyze tradeoffs between various training device features in developing a device configuration, and then conducts similar tradeoffs between different training device configurations. The development of OSBATS has been more theoretical than the typical decision support system or aid, but shares many of the attributes of the standard decision aid. The tools or modules that comprise the model address the following activities: a) the clustering of tasks for developing coherent training device configurations, b) the identification of optimal instructional features for a task cluster, c) the specification of optimal fidelity levels for a task cluster, d) the selection of the minimum training device family that meets training requirements, and e) the allocation of training resources in the family of suggested training devices. The final output of the OSBATS model is a functional description of the optimal set of efficient training devices given the tasks, training criteria, and cost constraints.

INTRODUCTION

The development of training systems is a complex undertaking that uses behavioral principles of learning to convey specific content-domain skills and knowledges. Training systems often incorporate training devices that are as complex as (and sometimes more complex than) the actual equipment that they are designed to provide instruction about. A fair amount is known about how training systems should be designed and implemented, and what the varied tradeoffs actually mean in terms of performance, training effectiveness, and overall cost. Within that large complexity is the "smaller" problem of designing a training system strategy based on training devices. Although there is considerable amount of data about specific training devices as used within specific training systems, there is no organized body of information necessary to build effective training device based systems or segments (5). As a result, the design of effective training devices is an effort that is fraught with imperfect data, opinion-based design rules, and an increasingly large number of choices in the large array of technologies that can be used to address any single training problem.

Training Devices

The goal of training device concept formulation is to propose a training device that meets training requirements at minimum cost, or provides the maximum training benefit for a given cost. This fits the spirit of Hall's definition (4) of optimization - "securing the best fit between the system and its environment" (p.73). The approach to training device concept formulation that has always been used in the past is to rely on the experience and knowledge of engineering and education professionals. This process has in no way approximated optimization.

One major problem area for training device developers is the range of information required for the large number of tradeoffs that must be made in order to arrive at a concept for an effective training device. Any tasks identified as requiring a training device solution must be analysed in order to understand and explicitly state the training device configuration required to meet the task

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training goals. This requires that the to-be-learned aspects of the task equipment and environment be identified, the technological options for simulating the necessary aspects of the equipment and its environment must be known, and the cost of using the technology in this particular way be known. The reliability and maintainability of the training device as conceived, the effectiveness of the training device in teaching the requisite skills and knowledges, and how the training device will or should be used are all prime concerns of the training device developer during this process.

A problem with this detailed approach is that when new technology, or improvements arise, the experts must estimate it's effectiveness and attempt to apply the technology appropriately. Individuals involved in training device design are seldom exposed to reliable information about how that applied technology actually works in the training system. The process of developing training devices would thus be improved if there were some way for designers to access and use training device and system evaluations, research experiments, and the combined experience of school professionals.

Design Aiding

The U.S. Army Research Institute for the Behavioral and Social Sciences and the Project Manager for Training Devices have embarked on a research and development program that addresses the problem of training device design. This program is an attempt to organize the large body of training technology and learning theory currently available, and develop an implementable model for aiding training developers in evaluating training device altenatives. The initial effort has been in the development of a model that provides tools for doing tradeoff analyses of training device configuration concepts. The prime contractor in this effort has been the Human Resources Research Organization (HumRRO). Together we have developed a model named the Optimization of Simulation-Based Training Systems (OSBATS). The OSBATS system is computer based and is structured to use databases and rule-based procedures interactively during the training device concept development process. Given the users choice of constraints and assumptions, different users may develop different solutions for the same problem, but the differences will be based in design rationales and have a supporting audit trail automatically provided.

The OSBATS tools are designed to aid the developer in providing an answer to the question "how much simulation is enough?" The tools have been developed by taking an innovative, theoretically based, top-down analytical approach. Army tasks were selected as a basis for analysis, since that information was more readily available. Future efforts will focus on detailing the data at the skill and knowledge level, so that model information will be more robust in application. The central question is need for simulation (ie. fidelity) versus the cost of providing the appropriate levels of simulation, hence the central module is a tool for Fidelity Optimization. Training effectiveness is also influenced by the instructional basis, and instructional features also have a significant effect on the cost of the training device, which led to the inclusion of an Instructional Features tool. The fidelity and instructional features modules approaches work best when the tasks form a coherent cluster of simulation needs. This led us to a Simulation Configuration tool, which clusters tasks in terms of simulation requirements and fidelity based cost estimates.

The problem of coherent training device design has another major factor, separate from instructional considerations. The cost of developing and using the training device must be considered in order to be efficient in training. Cost is driven by the time required to train each task on the training device. The concept formulation process must ensure that the minimum family of devices for the tasks are developed, and the Training Device Selection tool serves this purpose. Time in training programs is also limited, and constraints are imposed by student flow. These factors and the training plan help determine the numbers of training devices required, which in turn effects training program resources. The Resource Allocation tool estimates the number of devices needed to meet requirements, working to derive the optimal family of training devices for the tasks, training resources, and student flow.

A few more details about what we mean by optimization are necessary to further explain our approach. In terms of training devices, an optimal choice is one that returns the most for the least, meaning devices that produce the greatest gain in student skill and knowledge for the time in training, the investment expense, and the operating cost. The identification and prediction of gains in skills and knowledges is not a trivial data collection problem. The gain or benefit can be an increase in the amount learned, an increase in proficiency, or a decrease in the time required to learn a set amount of information or reach a set level of proficiency. The realm of resources presents another hard data problem in attempting to optimize training devices. We are attempting to cover the greatest part of these resource areas by including all development, maintenance and overhead cost into one measure. The number of students, number of devices required, and minimal family of training devices for training the task set are also considered, but separately from cost.

DECISION SUPPORT

The OSBATS is a decision support system or decision aid that should increase the timeliness, amount, and quality of information available for Army decision makers during the training device concept formulation process. As Sprague and Watson (9) have pointed out, all decision support systems are composed of three basic parts or subsystems: the data that the system uses, the user interface, and the decision models that use the data to recommend decisions. The three subsystems for OSBATS are briefly discussed in the next few paragraphs.

User Interface

The user interface is a critical part of any decision aid, and serves as the basis for user understanding and confidence in system processes and recommendations. The OSBATS model is meant for use by engineering and educational professionals involved in training device concept formulation efforts at the office of the Project Manager for Training Devices (PM TRADE). Obviously the more naive a user is the simpler the interface must be. Also, the more a user knows about the process, the more justification for recommendations are needed, along with shortcuts for situations where the user is satisfied with the system. Users are also considerably interested in being able to manipulate the system, to explore different problem options. The OSBATS system attempts to deal with a wide range of users through the use of graphs and tables to present results of the tradeoff analyses performed and the information used in making the analyses. This provides the user with different ways of viewing the results. The user inspects and modifies the information by using a mouse activated set of commands and selections. The results are inspected along with the data and reasoning used in the analyses by using the same interface. The system is also being modified in order to produce output data files or simple printed reports of the results of the analyses.

Database

The data subsystem required for decision aids usually consists of a database of information; procedures for collecting, organizing, and entering the data; and an inquiry or retrieval system for accessing the data. There are two ongoing contractual efforts involved in developing various aspects of the required data subsystem (2, 3). The goals of these efforts are to detail the internal data and rules required for the models; to describe the input data required for users to initiate work with the models; to identify or develop methods for collecting, converting and/or transforming the data to model usable formats; and to define the necessary framework for organizing the varied rules and data required by the optimization efforts.

As indicated above, there are two types of data required to support the functioning of the model tools. The first type of data, called resident or internal data, covers the unchanging or slowly changing information and relational rules involved in the generation of options, tradeoffs, and configurations. The second type of data required by the models is situationally specific data, the data used to initiate execution of the models.

The resident or internal data cover general task characteristic based rules for fidelity options, types of instructional features, fidelity and instructional feature cost estimates, learning parameters, and so forth. These data and rules will be developed through analytical evaluations and data collection efforts, including experiments designed to verify certain assumptions and the hypothesized relationships within the model. The resident data include rules about the relationships between the resident data values and the input data. These resident data will be available to the OSBATS system through a modifiable data base system.

The situationally specific or input data are used to initiate execution of the models. These data include descriptions of the tasks to be taught, the task performance criteria to be met by the training, the current training investment and operating cost projections, the type of instructional approach, number of students, number of instructors, time for training each task, etc. These data should come from the analysis of training requirements conducted during the development of the program of instruction.

The data collection work currently underway is focused on the resident data and includes detailing the data required for the models, planning for and acquiring the rotary wing operations task data, and developing a prototype database system for the resident data. It should be made clear that the resident data are related to the input data in terms of the descriptive task variables used, such as standards, conditions, equipment, cognitive and psychomotor classifications, criticality of performance, etc. These data must be acquired from many sources. The resident database uses these variables within rules that specify applicable fidelity dimensions, fidelity levels, and instructional features for specific tasks. These rules must have explicitly defined task variables in order to be structured for general use across tasks. For example, a simplified fidelity rule about how much platform motion to include (a fidelity output variable) might require information about the entry level proficiency of the student and the degree to which kinesthetic motion cues are used in guiding task performance (two variables and associated values). This forms the basis of the internal structure of the resident rule, and directly specifies the types of variables and values to be collected for an analysis session. In this way the internal resident data structure must be linked to the structure of the input data. The system would not be able to make a recommendation on the degree of motion unless the required input data for the rule were provided.

As discussed above, the domain of training device design requires reliable information about applied technology and the implications for training systems. Hence the resident decision rules and models come from varied sources, including psychological experiments and theory, training system evaluations and validations, and subject matter expert opinion. The primary problem in this approach is the development of a reasonable framework, in addition to the expense and time required in organizing explicit information into a usable format. With the approach we have described here, we believe that a workable framework has been developed.

Models

The central tools within OSBATS are those that focus on specific instructional features and specific levels on identified dimensions of fidelity. The goal of the system is to prescribe a training device configuration that has the greatest benefit for the projected cost. The benefits are either experimentally based with reference to transfer of training or are estimated by experts. The costs used include the investment and operating cost of the training device over it's life cycle. As introduced above, the model consists of five conceptual tools:

1) Simulation Configuration Module - a tool that develops clusters of tasks sorted into the categories of part-mission training devices, simulators, and actual equipment.

2) Instructional Feature Selection Module - a tool that analyses the instructional features needed for a set of tasks and specifies the optimal order for user selection of instructional features.

3) Fidelity Optimization - a tool that analyses the set of fidelity dimensions and levels, then provides the optimal order for inclusion of fidelity dimensions and levels given the task set.

4) Training Device Selection - a tool that aids in determining the most efficient family of training devices for the entire task group, given the training device fidelity and instructional feature configurations developed.

5) Resource Allocation - a tool that aids in determining the optimal allocation of training time and number of training devices needed in the family of training devices recommended.

The OSBATS model was developed as a framework that allows the addition and insertion of new models for different aspects of the concept formulation process. Each of the five areas was identified through the analysis of the theoretical basis of the training device concept formulation process. Each of these modules is based on empirical information, assumptions, and hypothesized relationships. Each of the modules uses training system and task data to present options, tradeoffs, and recommended configurations to the users.

Fidelity in Simulation. The Fidelity Optimization module currently requires input data about the cue and response requirements of each task in the task set, in order to match those requirements to the appropriate fidelity dimensions. This supports the analysis of the highest cost drivers in the development of a training device, by selecting only the specific dimensions that are needed. The module then uses the cue and response information to select the optimal family of dimensions and levels based on the tradeoff between the benefit to training provided by each level and the cost of developing that level of fidelity. The model will evolve to include other cost aspects such as maintenance and life cycle operating costs.

The model functions by first calculating the benefit to cost ratio for each level in each dimension, then using a selection process to arrive at the most effective combination of fidelity dimension levels. There are two ways for the user to specify what is the "most effective" combination. One way is to determine the level of funding available for the training device; the model then identifies the most beneficial dimensions and levels for the task set at that level of funding. Another way is to specify the benefit (which represents training effectiveness) desired in training the task set, and let the module select the fidelity dimensions and levels needed to reach that degree of benefit.

The fidelity module provides several methods that enable the user to conduct "what if" analyses. One method is to restructure the task set by changing the tasks that are included for analysis. The user can eliminate a task that is driving a high level of fidelity along one or more dimensions, possibly arriving at a configuration that meets all of the fidelity requirements for the reduced task set for the projected available dollars. This recommendation would serve as a basis for discussions with the school about the need for more money to train particular tasks, or the need for restructuring the way the tasks are trained at the school. Another method for analysis is provided by reducing the levels within any fidelity dimension. This feature allows the user to force a higher level of some fidelity dimension at the start, or preclude a level from consideration. Finally, the user can use the feature to eliminate a fidelity dimension entirely. This allows the user to study what levels of benefit might be achieved for the same money on the other dimensions required for the tasks.

Instructional Feature Selection. The Instructional Feature Selection Module is used to select features that will improve the efficiency of training on the proposed training device. The module uses input data such as task training requirements and projected costs for task training on actual equipment. The module also uses internally resident cost data and applicability rules to select the features relevant to the task set, assign costs and calculate the benefit values for the each task and feature match. The benefit values are summed across all of the tasks to which they apply to arrive at a total feature benefit value. The benefit and cost are then combined as a ratio that provides a measure of how much increased efficiency can be acquired for the dollars spent. This ratio is used to order the instructional features along a curve. As with the fidelity module the selection method allows the user to choose the most beneficial instructional features for a constrained dollar amount, or to select a set of instructional features that provide the greatest proportion of benefit for the task set at the lowest cost.

The user can also conduct "what if" studies using the same functions as are available in the fidelity module. The user can restructure the task list under consideration by including or excluding tasks that require multiple instructional features or single, expensive instructional features. The user can also eliminate instructional features from consideration, which could change the ordering of suggested features. Finally, the user can force one or more instructional features to be automatically included in the package, which might show decreases in the optimality of the constrained instructional feature order.

FUTURE PROGRESS

The pre-prototype tools or modules have been individually developed and evaluated for their user interface and theoretical foundations during the winter and spring of 1987. The integrated prototype system has been delivered for evaluation of the complete model, and will be revised to increase flexibility and broaden applicability during the next year.

The major problem in this detailed approach to instructional features and fidelity is that there is very little or no available experimentally based information in the literature that has focused explicitly on the interaction of task types and fidelity (1). Some ARI theoretical efforts in the past have focused on the identification and characterization of training system and training device variables (5, 6, 8), but the amount of correctly structured information is limited. On the basis of this earlier theoretical work and a concept demonstration (8, 6), it does seem possible to structure empirical knowledge about the characteristics and instructional features of training devices in production rule formats. This requires careful analysis of the gross level training device evaluation reports that are available, in conjunction with the better research (e.g. 7).

The next version of the OSBATS model will borrow from expert system technology in order to incorporate processes that infer the requirements for instructional features and fidelity specifications from more basic information about the tasks being considered. The inference process will be implemented through a commercial authoring tool that supports a production rule architecture. The output of the production system will provide the input parameters required by the analytical portion of the OSBATS model. The higher level analytical routines and user interface functions will be retained from the current version of OSBATS. The next version of OSBATS will also contain direct connections to the commercial database being prototyped in the Database Development (3) and Data Collection (2) contracts.

The use of an expert system authoring tool and production-rule approach should allow for the collection of more accurate data without increasing the workload of the subject-matter experts who must provide many of the judgments required by the model. In addition it provides a framework for encoding what is known from the research literature. Finally, the format will allow for incremental growth of the model, accommodating future empirical and fundamental research.

Because the domain specific information used by OSBATS (e.g. fidelity dimensions and levels, instructional features) is represented in simple knowledge base files, new domains can be incorporated into the system without changing the functioning of the model. This will allow us to expand the prototype OSBATS from the current rotary-wing operations domain to other domains (for example, armored vehicle operations or electronic maintenance domains). It will also allow the incorporation of new modules (such an the instructor operator considerations module now under conceptual development). We are currently planning for the extension into another domain, and will be testing the practicality of the approach during FY 1988.

GENERALIZATIONS AND IMPLICATIONS

OSBATS is a theoretically based model that trades off the projected benefit of discrete features relevant to specific tasks against the cost of developing and fielding that combination of features. OSBATS is a flexible rule based system that will use expert system technology to represent what is known or surmised about the benefit of features and aspects of training devices in relation to specific tasks. OSBATS is an expert system based decision aid that doesn't model any single expert.

OSBATS represents the current movement into the development of decision aids that are designed to expand the number of factors that the average decision-maker considers, while increasing the speed with which decisions are made. The typical training device designer considers many factors in general ways during the development of a training device concept. Different training device designers consider different subsets of those factors. OSBATS and decision aids like OSBATS (in other application areas) support the decision maker in consistently considering as many aspects as can be identified, by using information from research and other experts. This decreases the individual-to-individual variance in the number and type of aspects considered in comparable cases. Decision aids like OSBATS also serve to increase the shared information base about the tradeoffs to be made, and can serve to increase the consistency of the decisions that are made. This is true even though the decision aids can be used on the same problem by two different users to develop two different approaches. The last great benefit for using decision aids like OSBATS is that the reasons for those differences are immediately present in the audit trail of user decisions that are made during the decision aid sessions.

Perhaps the most important point is that decision aids like OSBATS serve to identify what is not well known in particular domains. In codifying the research literature and the consistent experientially based knowledge of experts, information weak areas are identified that do not have any firm available answers. Many of these areas are known to researchers, although perhaps not all, but the primary benefit of the organizational process is to specify exactly what is known, what must be assumed, and provide a rough measure for prioritizing what should be investigated next.

REFERENCES

1. Ayres, R., Hays, R. T., Singer, M. J., & Heinicke, M., An Annotated Bibliography of Abstracts on the Use of Simulators in Technical Training. (RP No. 84-21), U.S. Army Research Institute for the Behavioral and Social Sciences, Alexandria VA, 1984.

2. Data Collection in Support of the Optimization of Simulation-Based Training Systems, Delivery Order 0002, contract N61339-86-D-0009.

3. Database Development in Support of the Optimization of Simulation-Based Training Systems, contract MDA-903-86-C-0382, University of Central Florida Subcontract 872830.

4. Hall, A. D., A Methodology for Systems Engineering. Van Nostrand Reinhold Co., N.Y., 1962.

5. Hays, R. T., & Singer, M. J., Research Issues in Training Device Design: The Organization of a Data Base. (TR 588), U.S. Army Research Institute for the Behavioral and Social Sciences, Alexandria, VA, 1983.

6. Hays, R. T., & Singer, M. J., Training System Design Guidance: Accumulating and Using Empirical Data. North Atlantic Treaty Organization Defense Research Group Panel VIII Symposium, "Transfer of Training to Military Operational Systems," Brussels, Belgium, October, 1985.

7. Rouse, W. B., Rouse, S. H., Hunt, R. M., Johnson, W. B., & Pelligrino, S. J., Human Decision-Making in Computer-Aided Fault Diagnosis. (TR 434), U.S. Army Research Institute for the Behavioral and Social Sciences, Alexandria, VA, 1980.

8. Singer, M. J., & Perez, R. S., A Demonstration of an Expert System for Training Device Design. Journal of Computer-Based Instruction, Vol. 13, No. 2, pp. 58-61, Spring 1986.

9. Sprague, R. H., & Watson, H. J., MIS concepts Part I, in W. C. House (Ed.), Interactive Decision Oriented Data Base Systems. Mason/Charter Publishers, Inc., New York, 1977.

ABOUT THE AUTHORS

Dr. Michael J. Singer is a Research Psychologist with the U.S. Army Research Institute for the Behavioral and Social Sciences at the Orlando Field Unit. His Ph. D. is in Cognitive Psychology from the University of Maryland. His work has primarily been in training and simulation with an emphasis on fidelity in the training situation. His interests also include memory, cognitive processes, mental modeling, judgment, and decision-making.

Dr. Paul J. Sticha is a Senior Staff Scientist with the Human Resources Research Organization in Alexandria, Virginia. He was formerly with Decisions and Designs, Inc., as a Senior Decision Analyst. He received a Ph. D. in Mathematical Psychology from the University of Michigan. His current interests are in the development of computer-based decision aids, mathematical models of human performance, applied decision analysis, and training technology.