DESIGNING SIMULATORS FOR PRACTICALITY

DR. CHRISS CLARK and DR. JAMES A. GARDNER
Honeywell Inc.

INTRODUCTION

Exploiting Simulation in Maintenance Training

The trend. There is a growing trend to exploit the potential benefits of simulation technology in the maintenance training environment. The Air Force, for example, is currently contracting for a simulator system designed to train organizational-level (O-level) maintenance procedures for ten subsystems of the F-16 aircraft. Procurement of simulators for training F-16's intermediate-level (I-level) maintenance procedures is under advisement. Current plans call for using simulators to train E-3A and selected F-15 maintenance as well. These procurements signify a fundamental change in the philosophy of maintenance training, which has relied almost exclusively to date on actual equipment trainers.

The incentives. The principal incentives for this revised approach to maintenance training are expressed concerns over the high-dollar costs of training and combat readiness, coincident with increasing pressures to curb defense spending. Approximately $12.6 billion are consumed annually by the military for direct training costs. The Offices of Management and Budget, and Secretary of Defense have issued directives requiring that all trainers and simulators be cost-justified prior to funding(1). Air Force Systems Command has likewise placed renewed emphasis on development and application of life-cycle cost techniques within all technology areas(2).

One significant impact on training costs is the number of trained personnel required to meet field demands. The Army, for example, has expressed interest in reducing maintenance personnel by seven to ten percent. This is a reasonable goal, however, only if the remaining, more limited maintenance force is better trained to compensate for the reduction. Unfortunately, evidence suggests that in many instances effectiveness of current training is far from adequate even for the existing maintenance forces.

An increased emphasis on "hands-on" practice of maintenance procedures (e.g., the Navy's Technical Hands-On Training System(3)) is intended to improve training effectiveness. In general, however, hands-on practice is severely limited with actual equipment trainers. Simulators, on the other hand, permit the practice of a full range of test procedures, including those that would be dangerous or expensive to practice on actual equipment.

Assessing Practicality

The question. A number of experimental programs have demonstrated the feasibility of using simulators as alternatives to actual equipment trainers for training maintenance personnel. The feasibility of applying simulation to I-level maintenance training was first demonstrated by Honeywell as part of an NAVTRAEQUIPCEN-sponsored program to simulate the ALQ-100 electronic warfare set and associated test stations.(4) The feasibility of simulating complex electronic maintenance equipment is no longer in doubt. The question becomes: are simulators practical alternatives to actual equipment for training purposes? This is the issue suggested by the conference theme, "Resource Conservation Through Simulation."

Practicality defined. Simulated maintenance equipment becomes a practical alternative when the associated life-cycle costs (LCC) are less than those of corresponding actual equipment trainers. This reduction can be effected primarily by substantial reductions in both procurement costs and the long-term maintenance costs for simulated equipment. In addition, the use of simulated equipment as a training device must at least maintain and preferably improve upon the level of training effectiveness achieved with actual equipment. Improved training effectiveness will be reflected in further LCC reductions.

Related research. A major on-going Air Force research program(5) is addressing the practicality issue with respect to I-level electronic maintenance training. The current program phase focuses on design, fabrication, and testing of a simulator-based system to provide hands-on training of Level-3 Apprentices to maintain the 6883 Converter/Flight Control Test Station (in support of the F-111D aircraft) and associated Line Replaceable Units (LRUs). The system incorporates simulations of the 6883 Test Station, four associated adapters, and three LRUs. A later program phase will include a comparative evaluation of current versus simulator-based 6883 training. Comparisons will include LCC analyses as well as training effectiveness evaluations.

The current paper. This paper seeks to identify some of the major factors influencing the practicality of simulators in the maintenance training environment -- factors that can effect resource conservation. This requires an understanding of what simulator-based training systems are and what resource demands are levied by current training approaches. To effect maximum resource conservation, the design of simulator-based training systems must focus on the identified sources of leverage in existing training systems.

Numerous references are made to the Air Force's 6883 program to illustrate how resource conservation can be considered in the design of a training system. The 6883 Test Station is an appropriate vehicle for demonstration because it represents a general class of very expensive, complex, electronic test stations commonly found in I-level maintenance shops and currently used as actual equipment trainers as well. Therefore, many considerations made with regard to providing simulator-based training for the 6883 can generalize with reasonable accuracy to a large number of similar devices.

SIMULATOR-BASED TRAINING SYSTEMS

Definitions of simulation and simulators abound(6). Nonetheless, certain general features characterize nearly all simulator-based training systems. First, simulator-based training systems incorporate devices that duplicate, in varying degree, the appearance and operation of selected actual equipment. The resultant "simulators" range in complexity from simplistic cardboard mock-ups to the very sophisticated flight simulators used in pilot training. The essential feature is that the simulators provide "sufficient" realism: 1) to evoke and permit practice of specified job-related tasks, and 2) enhance transfer of the learned skills/knowledge to real world job environments. In the design of all simulators, certain aspects of the actual equipment are deliberately omitted; that is, the simulators are characterized by less than 100% engineering fidelity. The simulators become training devices when these omissions are based on careful identifications of how the devices are to be used in the training environment -- what persons with what entry-level skills/knowledge are to be trained to perform what set of tasks to what level of proficiency under what conditions?

Second, simulator-based training systems may incorporate supporting instructional features -- trainer-unique features and capabilities not inherent to the actual equipment. These features could include carefully controlled learning situations, step-by-step monitoring of trainee actions, performance feedback, automated instruction, and well designed student and/or instructor station consoles. Again, however, the requirement for these various adjunct features must be based on a clear specification of intended simulator trainer use.

Third, within the context of Honeywell's Automated Electronic Maintenance Training (AEMT) concept, simulator-based training systems are closed-loop (i.e., computer-driven and computer-sensed) systems designed primarily to provide hands-on practice of required job skills. Not only does the computer control the training environment (e.g., by simulating a carefully selected set of maintenance problems to which the trainee must apply relevant skills and knowledge), but it also monitors the trainee's step-by-step actions, compares these actions with prescribed procedures, and informs both the trainee and his instructor concerning the trainee's performance. This feedback is intended primarily as a learning aid and only secondarily as data for student records. The specific content, format, and frequency of that feedback vary in accordance with this aim.

TRAINING DEMANDS ON RESOURCES

The costs of current maintenance training systems fall into two general categories: personnel (student, instructor, and support) and equipment (procurement and support). Of these two, personnel costs account for the major portion, although the degree of savings leverage associated with that category varies with the particular system.

For example, personnel costs vary from approximately half of the total system costs in the case of the A-7 Heads-Up Display (HUD) system (7), to 97 percent of total costs in the case of the Navy's Basic Electronics and Electricity (BE&E) Program (8). Because the HUD and ALQ-100 Electronic Warfare systems are relatively equipment-intensive systems with low student flows, comparable savings can be achieved in both equipment and personnel categories. In stark contrast, the BE&E program is extremely personnel-intensive, inputting over 7000 students per year, per training site. Although the actual training equipment in the BE&E course may be cost effectively simulated, the real leverage rests in reducing personnel costs, especially students. Therefore, any BE&E simulation system must maximize training effectiveness to be a practical alternative.

The application of simulation to maintenance training could impact training-related personnel costs in a variety of ways. For example, simulator-based training systems have the potential to:

- Improve the instructor/student ratio, thereby reducing instructor costs.
- Reduce student on-board time, thereby reducing student costs.
- Reduce required maintenance force for training equipment, thereby reducing support costs.
- Minimize personnel required to incorporate curriculum and/or engineering changes, again reducing support costs.
- Reduce required number of field maintenance personnel, thereby reducing the required training throughput.

These areas of potential savings are addressed in subsequent sections of this paper.

DESIGNING FOR RESOURCE CONSERVATION

The key to resource conservation through simulation is careful training system design. To be effective, this design process must be guided by multiple considerations, including the following:

- Meeting training objectives
- Meeting without exceeding required functional capabilities
- User acceptance
- Improved training effectiveness
- Training system supportability

However, the first decision to make regarding the application of simulation to maintenance training is when not to simulate. Simulator-based systems cannot be assumed a priori to be the most practical approach to meeting the training need. Factors to be considered include: the projected student pipeline, the availability of inexpensive alternative training media, (e.g., sound-slides, video tape, movies, cardboard mockups), number of required training units, current training deficiencies, user acceptance of simulation, and the state-of-the-art in simulation technology. Indeed it is quite possible that no single approach is sufficient to meet the total training requirement; some combination of operational, simulated, and/or stimulated equipment together with traditional classroom approaches may provide the most appropriate training environment.

There is recognition of the fact that simulation should be implemented selectively. The Air Force Human Resources Laboratory (AFHRL) has recently awarded a contract to develop and apply a technique to identify areas of technical training within Air Training Command where high payoffs can result through use of simulation. This techniques is to be applicable across skills levels and will not be limited to avionics applications. The Army has likewise publicized its intent to sponsor a study to identify the areas of maintenance training for which reduced fidelity trainers can be cost-effectively substituted for standard, operational equipment currently used as trainers. These identifications are to be made on the basis of training level (institutional or unit), type and/or specialty (track vehicles, wheel vehicles, aviation, electronics), and skill (motor, cognitive or combination).

Design to Meet Training Objectives

The crucial first step in the design of any simulator-based training system is a front-end analysis. It is conducted to determine the training features to be incorporated not only in the simulator training device itself, but in the total training system. The resultant functional specification guides the subsequent detailed design and determines in large part the ultimate effectiveness of the device, thereby impacting both equipment and personnel costs. A recent AFHRL-sponsored program recommended and documented a process for the design of trainers based on behavioral information (9). The identifiable products of the front-end analysis may include:

- A listing of tasks/skills/knowledges to be trained. These constitute training requirements and are specific reflections of the fundamental purpose of any training system: to evoke prescribed changes in human behavior. They are a function of the ultimate behavioral objectives for the trainees upon completion of training and the level of skills/knowledge possessed by trainees upon entering training.
- An established set of training priorities. For example, a common goal in maintenance training is to place primary emphasis on detection of faults and isolation of their sources and to place secondary emphasis on performing the appropriate remove-and-replace (R&R) task. A few representative repair actions are usually required; in cases where the trainee is not asked to perform the R&R task, he is nonetheless asked to indicate what the appropriate repair action would be, given the simulated fault.
- Documents that specify the functional requirements of the related hardware, software, and courseware. These

documents are referred to as functional or performance specifications. While the training requirements and priorities are statements related to the trainee's prescribed performance during training, the functional specification establishes the capabilities and performances required of the simulator, or other training device, and of the system of which it is a part.

Although the functional specification does not contain the detailed design information such as would be required to cost and fabricate the simulator system (e.g., drawings, diagrams, theory of operation, parts list), it does constrain the detailed design.

The development of training requirements, priorities, and functional specifications requires that one address a number of critical questions. Typical questions include the following:

- What is the intended scope of the training system and how is the simulator training device to be used within that system? Will the simulator be the sole or even primary training equipment?
- What is the entering skill/knowledge level of the target trainee population? To what level of expertise are they to be trained?
- What are the deficiencies in existing training and what accounts for them?
- What is the set of on-the-job procedures that an individual of the designated exit-level skill is expected to execute? These prescribed procedures are a function of the accepted maintenance philosophy. The identified set will likely reflect both normal and degraded modes of operation. In the case of developing simulator-based maintenance training systems, significant effort is directed towards selecting a representative subset of realistic malfunctioning conditions to which the trainee is exposed so that he can practice fault detection, isolation, and troubleshooting techniques.

The identified maintenance procedures are further described in terms of specific actions (e.g., place 400 CPS and 60 CPS circuit breakers to ON position), associated man/equipment interfaces, and relevant cues (e.g., displays and indicator lights). These data are then cross-referenced with features of the actual equipment to identify a candidate set of equipment features and visual/functional fidelity levels to be reflected in the simulator design. Final selection of functional capabilities is based on such considerations as difficulty/importance of training the associated procedure(s), alternate training forums for the procedure(s) (including on-the-job training), cost considerations, and user biases.

In the case of selecting functional capabilities for the 6883 Simulator System, decisions reflect the preceding considerations plus an underlying philosophy of training by representative example. These selection criteria are perhaps best illustrated by the Data Transfer and Control (DATAC) drawer and power supply drawers. The DATAC (Figure 1) was selected for in-depth simulation because it is central to a variety of maintenance procedures. It is the principal technician interface through which automatic test requests are initiated, test modes are changed, and test results are displayed. Knowledge of its functions/operation is essential to operation of the entire test station. The training-by-example philosophy is reflected in simulation of the DATAC drawer interior. Although the hinged card frame assembly contains a full set of 56 simulated printed circuit cards (Figure 2), only 4 are removable and sensed by the computer. The remove-and-replace procedure is identical for any one of the 56 cards and, therefore, can be sufficiently well trained on a limited number of such cards.

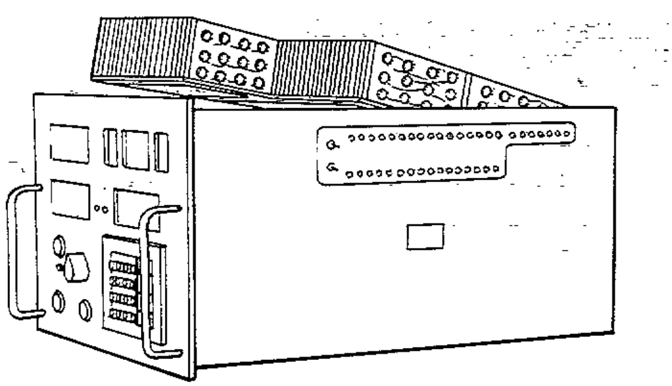

Figure 1. Simulated DATAC Drawer, Side View

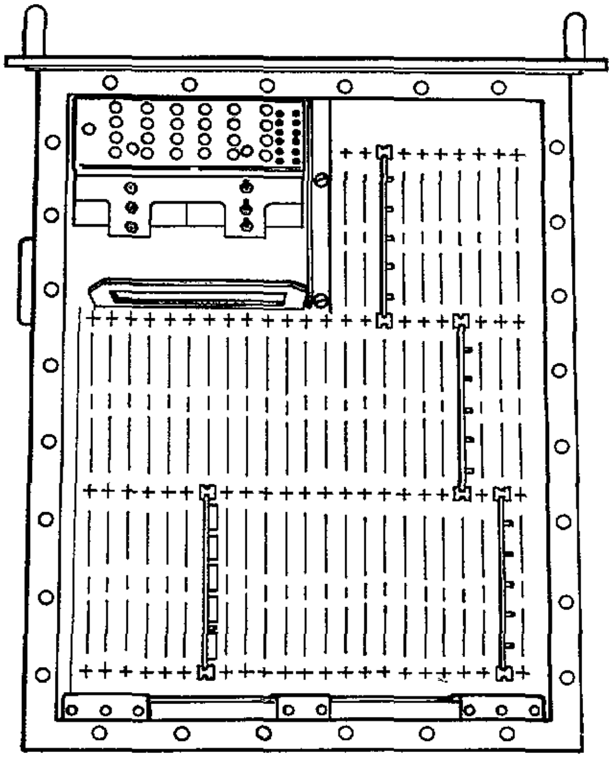

Figure 2. Simulated DATAC Drawer Interior, Top View

For similar reasons, only a single power supply drawer is simulated internally, although the 6883 has several power supplies. Maintenance procedures, simulation techniques, and the skills and knowledge required for troubleshooting are common among most power supply circuits in the 6883. This simulation philosophy is reflected throughout the functional design of the test station and LRU simulations. Figure 3 depicts the resulting variation in fidelity across the panels of the test station simulator. The 6883 Simulator consists of 28 metal photo panels, 3 pull-out drawers with simulated interiors, and an unmodified GFE oscilloscope, arranged in the appropriate 4-bay configuration. Selected front panels are represented completely with metal photos. Others are simulated using metal photos plus appropriately positioned functional components.

By making the types of tradeoffs just described, the 6883 Simulator System permits the trainee to practice the range of maintenance procedures that a 3-Level Apprentice must perform, without requiring unnecessary, costly simulator features.

Design to Meet, Not Exceed Required Capabilities

Several alternative detailed designs may satisfy the functional specification: the specification itself does not contain any explicit design decisions or choices among alternative design approaches. For example, the 6883 functional specification requires that the system permit the trainee to adjust a designated potentiometer within specified tolerance limits; the adjustment should be reflected on a corresponding meter. The detailed design of the simulated potentiometer (e.g., how it is sensed), the simulated meter (e.g., how it is driven), and related performance-monitoring software are not specified, although they are constrained by the functional requirements. In this case, the potentiometer and meter representations must bear sufficient visual similarity (visual fidelity) to and must also appear to function like (functional fidelity) their operational counterparts, with regard to the specified adjustment task. Moreover, the system must be able to sense the trainee's adjustment and to compare that adjustment with the prescribed procedure. How these functions are to be accomplished is not prescribed in the functional specification.

Caution must be exercised to avoid over designing the simulator system. To develop an engineering design for a system that exceeds the required functional capabilities merely increases cost without providing a corresponding increase in training effectiveness. For example, unnecessarily costly displays may be designed that provide rise times, resolution, or dynamic capabilities far beyond what is required for a simple GO or NO GO maintenance status check.

Carefully prepared functional specifications can often lead to dramatic reductions in the required fidelity of simulated controls and displays without negatively impacting training effectiveness. For example, a front-end analysis of the F-4N O-level Visual Target Acquisition System (VTAS) radar training requirement indicated that students already had received extensive experience with radar display interpretation prior to their entry to the VTAS course (10). It was only necessary for the students to detect the presence or absence of certain dynamic radar modes. Therefore, a simulation of these radar modes was simply constructed from a series of lighted segments which combine through computer control to create the appropriate display. By properly sequencing the lighted segments, the computer software duplicates the various dynamic, sweeping radar displays normally seen during VTAS checkout.

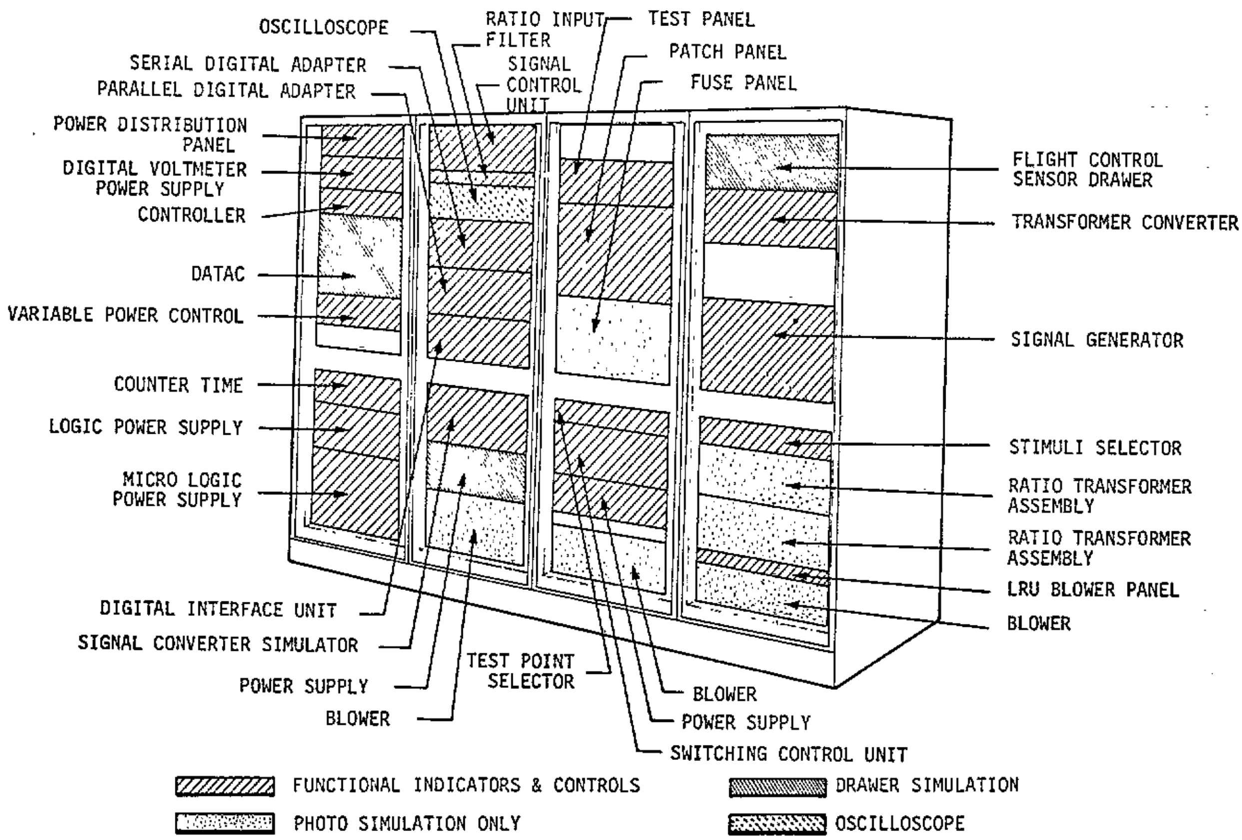

Figure 3. Panel-by-Panel Summary of Simulation Levels Required Across Test Station

Through a clear identification of the features necessary for effective training, similar cost-effective detailed design decisions can be made for such diverse topics as input/output response speeds, control resolution, meter motion, and waveform fidelity.

Overdesign is a potential pitfall in software design as well. Before any detailed software design is initiated, it must first be determined if the functional specification requires primarily procedural or modelled software. For many maintenance training tasks, it is only necessary to duplicate display-control interactions and to monitor trainee performance for specific step-by-step procedures defined in the system maintenance manual. Should the student make an error such as setting an incorrect switch or skipping a procedural step, the computer will halt the lesson, provide the appropriate feedback, direct the student to correct his error, and allow him to proceed with the lesson once he has made the specified corrective response. This procedural software design approach provides a low-cost solution to a range of maintenance technician tasks having clearly defined actions and equipment responses.

In contrast, some functional specifications may require the simulation to model the actual equipment operation. This modelled software design approach requires the development of a polynomial mathematical equation of each instrument as well as for the overall system control and display interactions. The student may set controls and make adjustments in any order he chooses, and the equipment will respond appropriately. Student performance measurement in a modelled system is correspondingly more complex due to the more ambiguous performance criteria. The greater complexity of modelling software is reflected in greater development and modification cost.

Design for User Acceptance

The argument for taking the most simplistic design approach which satisfies explicit requirements of a functional specification must be tempered slightly by concern for user acceptance. Traditionally, flight simulators have been characterized by extremely high engineering fidelity -- to the point that they could be considered aircraft without wings -- and the cost of such simulators sometimes exceed that of the operational aircraft themselves. This can be attributed to two major factors: 1) limited data concerning the features of the aircraft system that are required to train the mission, and 2) the demands of users for a training device that "feels like, looks like, smells like..." the real thing. The user's conviction is frequently that the actual equipment is the best training environment; simulators somehow represent a degraded training environment, but are "accepted" because they become the only reasonable alternative in light of government edicts to reduce costs.

The problem of overcoming the user community's resistance to simulator-based training where actual equipment is currently the norm and is a major concern for the maintenance training area, and must therefore, be considered in trainer design.

Design for Improved Training Effectiveness

Improved training can potentially effect substantial savings by:

- Reducing the number of required field personnel.
- Reducing training time, thereby making trained technicians available sooner and longer.
- Reducing the need to retrain inadequately trained personnel.
- Reducing the amount of time operational equipment and personnel are devoted to OJT.

Addressing current training deficiencies

The use of actual equipment trainers for maintenance instruction limits the effective training of many critical procedures. A well documented problem in current 6883 training, for example, is the frequent unavailability of a fully operational test station. This is a function of the equipment's inherent low reliability and the significant "down time" -- i.e., lost training time -- associated with required maintenance. Test station unavailability is especially pronounced in the training environment due to intermittent use of the station, station misuse by trainees, less experienced maintenance personnel, and training facilities' low priority with respect to receipt of needed replacement parts. Consequently, the effectiveness of current 6883 training and training for comparable equipment is suspect.

The low availability of actual equipment trainers together with concern for student and equipment safety limits the trainee's "hands-on" practice of general maintenance procedures. In particular, use of actual equipment trainers severely limits the range of equipment faults and emergency conditions to which trainees can be systematically exposed. Consequently, trainees are not permitted sufficient practice troubleshooting problems they are likely to encounter in the field. Duplication of a controlled set of equipment faults generally requires physical insertion of costly prefaulted hardware components. Permanent damage to the actual equipment is simply not an option. Simulator-based training systems, on the other hand, permit the insertion of preprogrammed malfunctions upon instructor command. The simulator-based system is decidedly more flexible in training situations.

Providing added instructional capability

A major advantage of simulator-based training systems is the closed-loop nature of the computer driven and computer sensed events. Three-Level Apprentices, for whom the 6883 Simulator System is designed, are not permitted to practice "free-play" troubleshooting techniques. Therefore, a system that forces strict adherence to prescribed procedures is appropriate. HRL's original RFP for the 6883 recognized this basic maintenance philosophy and required that any candidate simulation system not permit the trainee to advance if he deviates from prescribed procedures. This requirement reflects the theory that learning is optimized by not permitting practice of incorrect responses. A computer-based, closed-loop system is ideally suited to such a requirement.

Furthermore, because the computer can monitor step-by-step trainee performance and can provide appropriate preprogrammed feedback/guidance to assist the trainee as required, the instructor is freed from many of the routine tasks of "instruction." This could result in improved (i.e., lower) instructor/student ratios, thereby effecting personnel savings.

A related, often touted "advantage" of computer-based (or other programmed instruction) systems is that they permit self-paced learning. Accordingly, trainees need spend no more time in training than their own rate of progress demands. This is an advantage, however, only if the total training or career plan is structured and managed to accept a continuing flow rather than periodic batch delivery of trained personnel. Little is gained by a self-paced training segment if upon completion the trainee must mark time before he enters a subsequent lock-step training segment or before he receives an appropriate field assignment.

Performance measurement. A critical factor in improving training effectiveness is appropriate performance measurement. Performance measurement refers to the reduction of the trainee's step-by-step performance data to meaningful indices. These indices can reveal problem areas that might otherwise go unnoticed in the overwhelming quantity of data that a computer-based system can monitor.

Among the various performance measures maintained by the 6883 Simulator System, for example, are counts of each trainee's procedural errors in various lesson segments; how often does he deviate from the prescribed sequence of actions outlined in the appropriate maintenance manual? Consistently high error counts might suggest that the trainee is simply negligent in attending to the manual's instructions or, alternatively, that the manual itself is not clearly written. The latter possibility can be explored by examining the error counts of other trainees to determine if they are erring on the same steps. If so, the computer-driven lesson material might be revised to provide clarification at specified points in the lesson to compensate for the manual's ambiguity.

In addition to serving as instructional aids, appropriate performance measures provide a means of assessing whether the trainee has met final performance criteria. This could reduce the chances that inadequately trained personnel would be released into the field.

Design for Supportability

Increased interest has been demonstrated recently in the reduction of life-cycle system support costs. This concern is reflected in the recent procurement of F-16 O-level maintenance simulators based upon the total system life-cycle cost, rather than mere hardware acquisition costs. To achieve this objective of low life-cycle support costs, a number of issues must be addressed during the system design including:

- Simulator System Maintenance - is contractor or organic maintenance the most cost-effective solution? What self-test capability is necessary? What spares inventory is appropriate?
- Simulator System Expandability/Flexibility can the simulator be cost-effectively modified or expanded? If major changes are made, do these require a complete system redesign?
- Configuration Management - if changes are made to the operational equipment, how are these changes implemented and controlled on the simulator?

Simulator system maintenance. Any practical alternative to actual equipment trainers must be reliable, easily maintained, and thereby consistently available for training. Meeting these criteria impacts significantly the costs associated with replacement parts and the required maintenance force. Total spares support for the VTAS O-level maintenance simulators delivered to the Navy and Marine Corps, for example, accounted for only 2.5 percent of the simulator system cost. This figure is in sharp contrast with the more usual 10-20 percent spares cost associated with support of actual equipment trainers procured at significantly higher costs. Moreover, the required maintenance time to date on the VTAS trainer has been negligible.

Provision for long-term maintenance of simulator-based training systems is a controversial topic across the Services. If the military assumes maintenance responsibility for these devices, is there need to establish a dedicated career field for simulator maintenance personnel? Moreover, what modifications must be made in existing policies to accommodate maintenance of this new breed of training devices? Air Force Logistics Command (AFLC) policy, for example, requires that spares be kept in inventory for only a limited period of time, after which they are discarded. It is possible that given the anticipated reliability of simulator systems, the demands on inventoried spares would be so few and infrequent that the spares would not be in the inventory by the time they are needed. An alternative approach to the maintenance issue is to procure full contractor maintenance. However, this requires a level of confidence in the contractor's continued commitment to the simulator-based trainer market. The long-term maintenance issue is complex and far from resolution at this time.

In the near-in case of the 6883 Simulator System, current plans call for a hybrid approach to maintenance, involving participation by both the Air Force and Honeywell. The simulation hardware is designed to be repairable to the component level by 5-Level Air Force Specialists. Prior to delivery of the system, Honeywell will conduct a maintenance training program that will equip a small (2-4) team of instructors to perform periodic, preventive, and corrective maintenance on the 6883 Simulator. These same persons will critique maintenance manuals to be delivered with the system. Final versions of the documentation will reflect their comments.

Major system maintainability design objectives include requirements for no unique maintenance skills of this specialist and requirements for the fewest possible preventive maintenance procedures and equipment alignments. Off-the-shelf, locally available system components are used wherever feasible. A detailed list of recommended spares will be delivered to the Air Force for procurement consideration.

Automated self-test and fault-isolation procedures are being provided for the system interfaces and simulation hardware. Software programs are being provided to permit daily automated status checks of the simulator prior to student instruction. Other, more detailed fault-isolation programs under development permit rapid fault isolation to major replaceable assemblies and cards.

All computer and peripheral equipment will likely be totally supported through a separate contract with Honeywell Information Services.

Expandability/flexibility. Modifications to actual equipment trainers can require major resource commitments. Extensive retrofitting of field equipment leads to costly, lengthy onsite modification of the corresponding training equipment, with the coincident loss of training time. Major model changes often result in scrapping the existing trainer for a replacement model. Even minor changes to the trainer to increase its capabilities can be expensive if the system is not designed to accommodate changes.

With proper design, the impact of changes can be minimized in simulator-based training systems. Many extensive revisions can be accommodated largely through simple software changes and low-cost simulated hardware changes. Even major model changes can be reflected without complete system replacement.

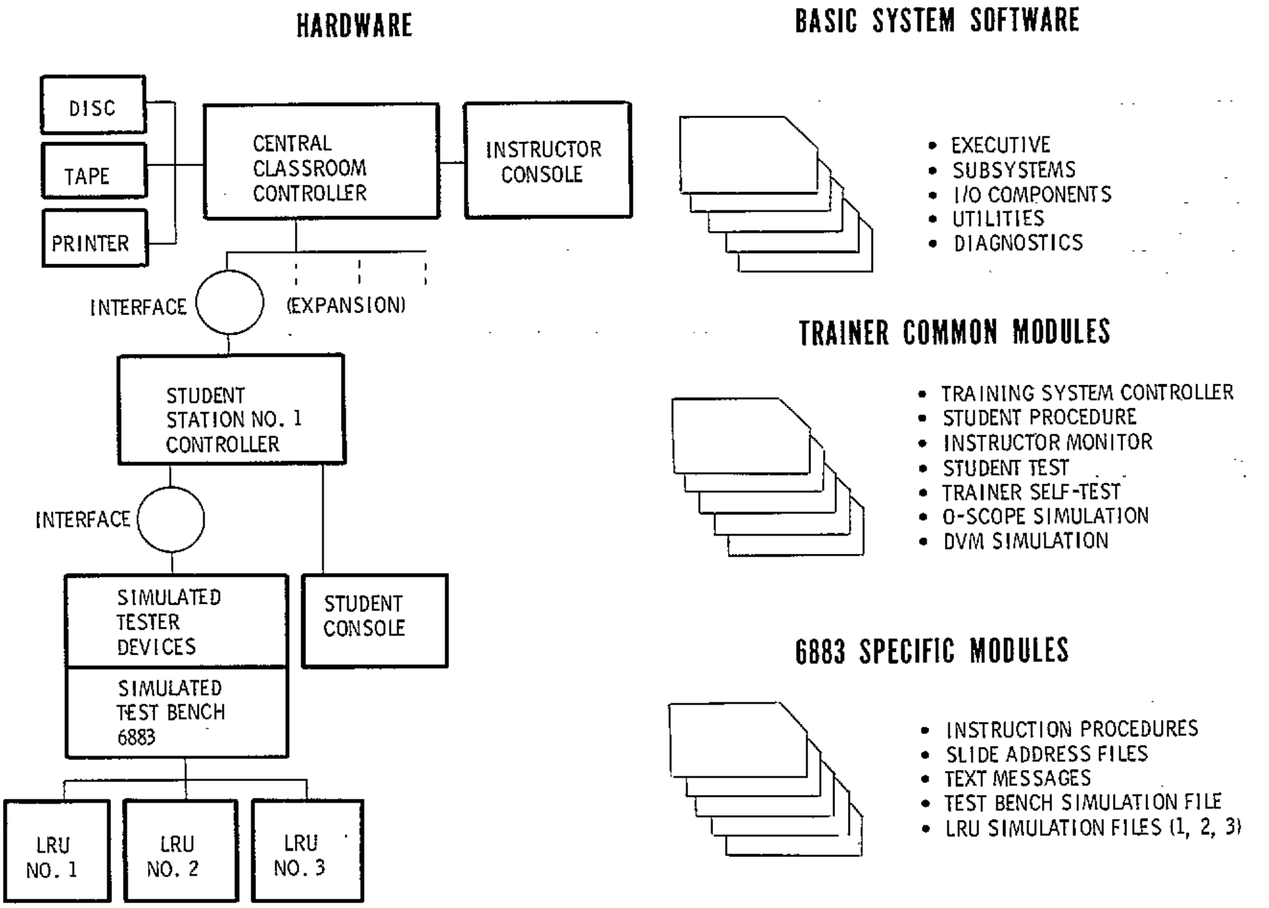

Figure 4. 6883 Simulator System Hardware and Software Modules.

The design of the 6883 Simulator System reflects concern for expandability/flexibility. The 6883 Simulator System is a multicomputer system which drives simulations of the 6883 Test Station and associated LRUs through appropriate interface hardware. Student actions on the simulated equipment are sensed by the computer through the same interfaces. Appropriate student guidance and feedback is provided by a CRT/keyboard and random-access slide projector. Student performance is recorded by the computer system and is output to a cassette tape and high-speed printer for recordkeeping. Figure 4 illustrates the training system hardware block diagram.

A minimum of three additional simulator training devices, different from the 6883 can be driven by the Honeywell 716 computer that is acting as a classroom controller. This feature accommodates the Air Force's long-term need for increasing numbers of simulators to meet their training requirements. Moreover, as the focus of training changes with the evolution of test equipment, the hardware system configuration developed for the 6883 can adapt - requiring only the replacement of obsolete simulation hardware with updated simulations; major system components (e.g., student console, student station controller, interfaces) can be reused with the replacement simulation.

The software and courseware architecture are similarly designed for flexibility (Figure 4). As additional or replacement simulations are incorporated into the system, only the data base modules specific to the new test equipment must be added to the software. Instructional materials or courseware are prepared in a manner that facilitates generation and/or modification of lesson materials by instructor or support personnel. This becomes an especially important feature when reconfiguration of equipment requires changes in the training course content. These kinds of considerations are especially important when designing trainers for developing systems (e.g., F-16). Numerous engineering changes should be anticipated, and a simulator system designed for maximum modifiability can minimize the cost impact of those changes.

Configuration management. The procedures for implementing and controlling changes to the simulator are not yet clearly defined. It is possible that the configuration management (CM) system for simulators will be different from that required for actual equipment trainers. The CM system must process all changes made to the actual equipment, determine if those changes impact the operation and/or effectiveness of the simulator, and process the resultant changes to the simulator software, hardware, courseware, or documentation.

Because the simulator operates in a manner different from the actual equipment and incorporates only a selected subset of all possible hardware features, only a small number of the original changes need be made to the simulator. Changes unique to the training system (e.g., added instructional features) may also require specialized CM procedures to assure that those changes do not cause the simulator to function differently from its operational counterpart, resulting in negative training. It is also unclear if the differences in complexity between the simulator and actual equipment impact the CM procedures required. Further study is needed to define the most cost-effective procedures to employ for simulator configuration management.

The Air Force Human Resources Laboratory (AFHRL) intends to examine alternative CM solutions for the 6883 Simulator System. Hopefully, through their study, a better understanding of the issues will evolve.

SPECIFICATIONS & STANDARDS APPLICATION

A remaining consideration that can significantly impact the cost of fabricating and documenting training systems is the application of accepted military specifications and standards. Indiscriminate application of existing specifications and standards developed for operational equipment, appears unnecessary, costly, and often inappropriate as the training philosophy shifts to replace actual equipment with simulators. Indeed full compliance with these specs and standards nullifies many of the potential benefits of low-fidelity simulation. The 6883 program produced a functional specification that can serve as a model for specifying future simulator-based training systems. Although MIL-STD 490 served as a guideline for organizing the 6883 document, deviations from that prescribed organization were incorporated, where appropriate, to accommodate the trainer-unique material discussed. Likewise, fabrication of the 6883 Simulator System is in accordance with Best Commercial Practices. This permits, for example, using non-ruggedized (and thereby less expensive) computers and simulation equipment. Suspension of the traditional military standards governing equipment fabrication is appropriate given that the simulator system is intended for classroom rather than field use. It will not undergo the routine disassembly, transport, and reassembly (at potentially unfavorable sites) for which operational test stations are designed.

A very recent Department of Defense directive (DOD Directive 4120.21) recognizes the need to reassess the strict enforcement of existing specifications and standards. The revised policy directs the services to establish procedures for the selective application and tailoring of specifications and standards, to impose only "essential system needs," to avoid "blanket contractual imposition," and to solicit recommendations from prospective contractors. These procedures apply throughout the procurement process; each program is required to document the extent to which specifications, standards, and data item descriptions have been modified.

OPEN QUESTION

Numerous studies (e.g., 11, 12, 13) have concluded that simulators train equally as well as operational equipment alternatives. However, most of these studies have suffered from the lack of adequate measures of transfer of training.

The Air Force Human Resources Laboratory recognizes this deficiency and is initiating a formal program to determine the relative merits of simulator-based training. A formal training-effectiveness analysis of the 6883 system will be conducted by AFHRL to assess the practicality of I-level maintenance simulation. The relative merits of actual equipment-based and simulator-based training will be contrasted through a comparison of students trained using the present operational 6883 Test Station and those trained using the simulator. A range of simulation techniques and training procedures has been specified to permit assessment of the relative effectiveness of different approaches. Detailed performance measures are specified which far exceed the instructor's immediate needs. These data will be recorded on cassette tape for later statistical analysis and can provide insight into both the simulator training effectiveness and the student's learning process. Finally, the hardware design incorporates a number of features which facilitate data collection and system modification. Through the inclusion of such additional hardware, software, and courseware features, an effective evaluation of the feasiblility and practicality of maintenance simulation will be possible.

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ABOUT THE AUTHORS

DR. CHRISS CLARK is a Principal Research Scientist at Honeywell, Incorporated, Minneapolis in the Training and Tactics Technology Section of the Man-Machine Sciences Group. She is chiefly involved with the design and development of military training systems incorporating simulator training devices and is currently principal investigator responsible for the training aspects of a research development effort sponsored by the Air Force Human Resources Laboratory to design, construct, and deliver an F-111 6883 Converter/Flight Control Test Station Maintenance Trainer. She holds an A.B. degree in mathematics, and an M.A. degree and a Ph.D. in psychology.

DR. JAMES A. GARDNER is a Project Manager for the Training Systems Program Office at the Systems and Research Center (S&RC) at Honeywell, Incorporated in Minneapolis. He manages a program sponsored by the Air Force Human Resources Laboratory to design, construct, and deliver an automated intermediate-level maintenance trainer for the F-111 6883 Converter/Flight Control Test Station and directs development programs in simulation and maintenance training technology. He was formerly a program manager of a project sponsored by the Naval Air Rework Facility to develop and deliver maintenance simulators for the AN/AVG-8F-4N Visual Target Acquisition System (VTAS). He has participated in other studies in the development of maintenance training technology for such systems as the Navy's ALQ-100, ALQ-126, and BE&E programs. Before joining Honeywell, he was a field engineer for Sarkes Tarzian, Incorporated, where he was responsible for the development of commercial and educational television systems. He holds a B.A. degree in psychology from Indiana University, and an M.S. degree and a Ph.D. in psychology from North Carolina State University.