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Investigation of Advanced Technology for Airway Facilities Maintenance Training

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This report describes the Phase one activities of a three-phase research plan. The first activity investigated the status of advanced technology in currently available Airway Facilities (AF) computer-based maintenance training. The second activity applied simulation, Expert System, and Intelligent Tutoring Technology in developing a prototype system for trouble shooting proficiency training.

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EXECUTIVE SUMMARY

A large percentage of Airway Facilities (AF) maintenance technicians will reach retirement age in the next 5 years. As the number of technicians decreases, increased demands are placed on the remaining workers. Each technician no longer specializes on a single piece of equipment, but is responsible for maintaining several different pieces of equipment. In addition, AF equipment has become more complex with advances in technology. Technicians must work hard to maintain proficiency on older systems while learning new systems. Advanced technology training systems may help to prepare large numbers of new technicians for these challenges.

The term "advanced technology" refers to the use of simulation, Expert Systems and Intelligent Tutoring Systems (ITS) features in the construction of a computer-based training system. Via interviews and site visits at the Federal Aviation Administration (FAA) Academy and regional training centers, it was found that currently available AF training does not take advantage of simulation, Expert System, or ITS technology.

This paper describes a demonstration training system that was developed to investigate the application of advanced technology to AF maintenance training. The demonstration training system was developed with the assistance of current and retired AF technicians for the Air Traffic Control Beacon Interrogator - Series 4 (ATCBI-4). The ATCBI-4 training system allows technicians to practice troubleshooting on simulated malfunctions with the help of an expert advisor. This system represents the latest extension to the Microcomputer Intelligence for Technical Training (MITT) software and runs on Office Automation Technical Support (OATS) machines in the Windows environment.

Preliminary evaluation of the system indicates that advanced technology training systems can be effective for AF maintenance training. Future plans include the development of an authoring system that can be used by AF technicians and training specialists to build similar training systems for other types of AF equipment and the development of an integrated information system which combines the training system with an expert job aid and an information retrieval system.

1. INTRODUCTION.

A large percentage of Airway Facilities (AF) maintenance technicians will reach retirement age in the next 5 years. As the number of technicians decreases, increased demands are placed on the remaining workers. Each technician is no longer able to specialize on a single piece of equipment, but is responsible for maintaining several different pieces of equipment. In addition, AF equipment itself has become more complex with advances in technology, further increasing the technician's cognitive workload.

Given these conditions, AF technicians are being challenged to maintain proficiency on older systems while learning new systems. Training on new systems often comes several months before the equipment is actually in place and functioning. By the time a technician is asked to apply classroom knowledge, much is forgotten. Advanced technology training systems may help rectify this problem by providing on-site, individualized, refresher/proficiency training.

2. BACKGROUND.

This report summarizes the work completed in the first phase of a three-phase research project on the application of advanced technology to AF maintenance diagnostic training. This section describes the three phases of work and defines what is meant by advanced technology.

2.1 THREE PHASES OF RESEARCH.

Table 1 lists the time schedule and major deliverables for each phase of the planned research. All three phases rely on the cooperation of technicians and other Federal Aviation Administration (FAA) personnel from the Southern Region and the FAA Academy.

The first phase of the work involved two major activities. First, the status of AF proficiency training was investigated to determine if advanced technology was currently being used. The results of this investigation showed that improvements could be made. Thus, the second activity produced a prototype of an advanced technology training system for AF maintenance. Sections 3 and 4 of this report discuss the two Phase I activities in greater detail.

In the second phase of this research, the prototype system will be evaluated for student and instructor acceptability. The feedback from these evaluations will be used to convert the prototype training system into a complete Intelligent Tutoring System (ITS). ITS's are described in section 2.2.

During Phase II, work will also begin on an AF Training Development System for authoring additional AF Maintenance ITS's. The AF Training Development System will allow the FAA to capitalize on the capabilities of advanced technology training by providing tools which facilitate the development of such ITS systems. The tool will also facilitate updating of the knowledge in such training systems. The first step will be to identify specifically who within the AF community will use the Training Development System. Based on the needs of target users, a functional specification of the AF Training Development System will be developed, as well as a demonstration Development System.

In the final activity of Phase II, the research team will produce a development plan and preliminary functional specification for an advanced technology AF Information System. The AF Information System will integrate training, real-time job aiding, and information storage and retrieval into one system. The specification will detail the functions of the AF Information System, based on an analysis of technicians' information needs. One major aspect of the development plan will explain how the expert knowledge base from the training system will be extended/adapted for use by a consultation model job-aid. The AF Information System would provide AF Maintenance technicians with a tool that not only supports maintenance proficiency, but also provides easy access to documentation and expert assistance while solving problems in real-time.

The third phase of the project will focus on the design and development of first the Training Development System and then the AF Information System. The research team will work with an ACD-350 advisory group, the Technical Requirements and Evaluation Team (TRET), to ensure that both systems are aligned with FAA expectations. Once the Development System is complete, two workshops will be held to instruct FAA personnel how to use the Development System.

TABLE 1. PHASES OF RESEARCH PLAN

Phase	Time Schedule	Major Deliverables
I	August 1991 - May 1992	Technology Status Report AF Maintenance ITS Prototype
II	May 1992 - February 1993	Complete AF Maintenance ITS Specification/Demo ITS Development System Plan for AF Information System
III	March 1993 - March 1994	Complete ITS Development System AF Information System

2.2 DISCUSSION OF ADVANCED TECHNOLOGY.

In its broadest sense, advanced technology refers to all recent innovations in hardware (HW) and software (SW) technology. Only a small subset of such technology is applicable to technical troubleshooting training. In particular, this research focussed on advanced technology extensions of traditional computer-based instruction. Figure 1 shows the generic model for traditional computer based instruction (CBI). As the figure illustrates, a student interacts with an instructional environment on a computer through some type of interface (typically, a monitor and keyboard).

In early CBI systems, the information presented by the computer was limited to monochrome text and simple line graphics. Today, there is a large amount of new (affordable) HW and SW technology that permits the capture, creation, display, storage, and retrieval of high resolution color graphics, animations, text, and video (see table 2). Such technology allows technicians to interact with high fidelity images of equipment and permit the storage of extensive amounts of information.

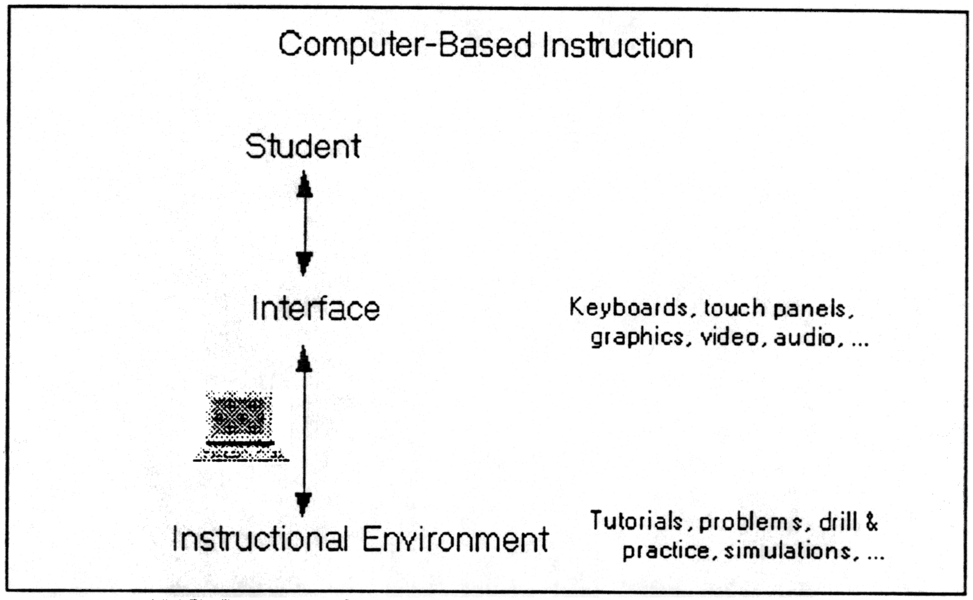

FIGURE 1. GENERIC CBI ARCHITECTURE

TABLE 2. EXAMPLES OF ADVANCED HW AND SW

Capture	Creation	Display	Storage/Retrieval
Scanners • Hand-held flat-bed • Black & white color Optical Character Recognition Still Video Camera Cam-corders	Word Processing SW Graphics SW • Paint packages • Object-oriented Animation SW • 2-Dimensional • 3-Dimensional	Graphics Adapters • VGA 640X480X16 320X200X256 • Super VGA 640x480X256 1280X1024	Compact Disc ROM Laser Disc Interactive Video Disc M-Motion Video Digital Video Interactive PC-VCR Bar-code Readers

Advances in interface technology have lead to the use of graphical user interfaces (GUI) that allow direct manipulation of the objects on the screen through the use of a mouse, touch screen, track ball, joy stick, or other input devices. Such direct manipulation devices, in conjunction with an interactive simulation, permit technicians to "learn-by-doing."

Instructional systems may also take advantage of the hypertext and hypermedia SW that has been developed. Hypertext SW permits developers to link text stored in a computer with any other text and to provide a means for readers to access these non-linear paths (Horn, 1989). Hypermedia applications extend this concept by including such components as video, graphics, animation, sound, and photographs. In a hypermedia instructional environment, students are not restricted to a single prespecified learning sequence, but rather may use links (provided by the instructional developer) to rapidly browse the instructional content and to choose an individualized learning path through the content (Nielsen, 1990).

Advances in SW technology have also addressed the issues related to making computer-based training more "intelligent." The work of cognitive scientists and artificial intelligence researchers over the past decades have focussed on such SW technology, including simulations, Expert Systems, and ITS's. Simulations model the functionality and behavior of equipment or systems and can be used as part of the instructional environment of a training system. Computer-based simulations have been shown to be an effective tool for diagnostic training (Johnson, 1981, 1987; Maddox, Johnson, and Frey, 1986). Expert Systems model the problem solving knowledge of a human expert in some specific area (Hayes-Roth, 1987). Often this expert knowledge is represented in the form of if/then rules; however, other forms of knowledge representation may be used (e.g., frames, scripts, cases, neural networks). Intelligent Tutoring Systems (Kearsley, 1987; Polson, and Richardson, 1988; Psotka, Massey, and Mutter, 1988; Sleeman and Brown, 1982; Wenger, 1987) extend the basic CBI structure by adding three models: an expert model, a student model, and an instructor model. Figure 2 illustrates the generic structure of an ITS.

This illustration represents the conceptual relationship between the student, the instructional environment, the instructor model, the student model, and the expert model. The expert model in an ITS is implemented as some type of Expert System. Conceptually, the expert model contains the domain specific knowledge that the student is to learn (e.g., rules for troubleshooting malfunctions in a piece of equipment). The student model is a dynamic hypothesis of what the training system thinks that the student currently knows (e.g., a list of parts which may be causing the current malfunction). This model is based on the observable actions that the student performs in the instructional environment and on the expert model (e.g., performed output test of X, viewed error indicators on control panel Y, etc.). The instructor model typically compares the model of the student to the model of the expert in order to provide feedback to the student (e.g., That test was unnecessary since...). The instructor model may also monitor the student model to decide when remediation is needed and to select future lessons or problems (e.g., if student solved N problems of type A without error, give a problem of type B).

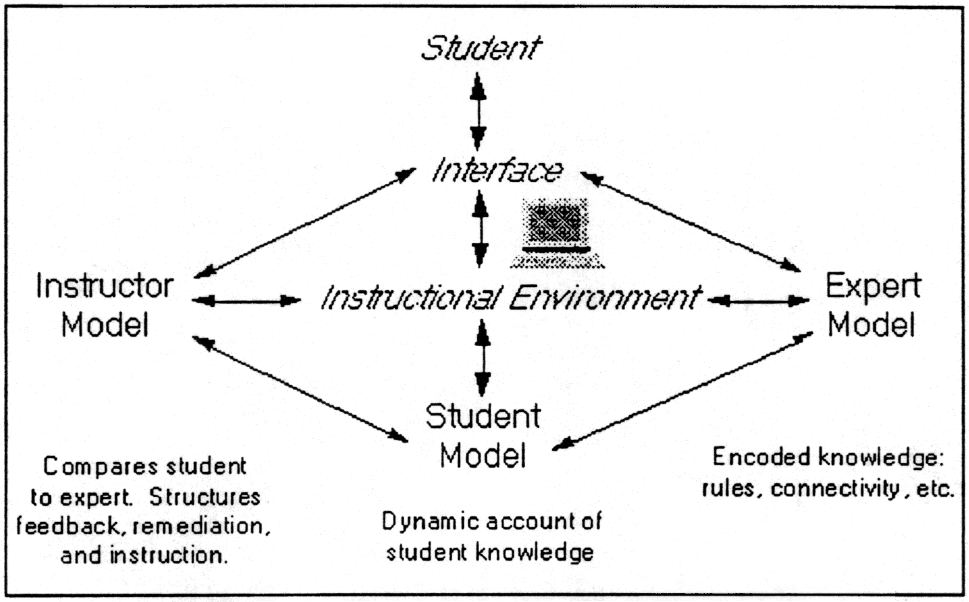

FIGURE 2. GENERIC ITS ARCHITECTURE

3. STATUS OF ADVANCED TECHNOLOGY IN AF MAINTENANCE TRAINING

Via unstructured interviews and site visits at the FAA Academy AF Training Development Unit and a regional CBI training center, Galaxy Scientific investigated the current application of advanced expert-system technology to AF maintenance training. Our informal investigation found that currently available AF training does not take advantage of simulation, Expert System or ITS technology. Rather, the majority of the current computer-delivered training is based on the older and more limited CBI architecture. The remainder of this section reports the current status of CBI in AF maintenance training in more detail.

3.1 OVERVIEW OF CBI WITHIN THE AF TRAINING CURRICULUM.

CBI is one of seven types of training delivered to AF personnel. Table 3 shows the distribution of AF courses across the seven types of training: resident training, correspondence study, out-of-agency training, CBI, on-the-job training, and field-conducted training. Whereas almost 50 percent of all AF courses are delivered through resident training (at the FAA Academy in Oklahoma City), only about 11.5 percent of all AF courses are delivered through CBI (at the regional training centers). However, the total number of resident students is typically only about twice the total number of CBI students. Thus, as one would expect, the relatively small number of CBI courses serve a comparatively high volume of students.

TABLE 3. AF TRAINING PROGRAM CURRICULUM

Type of Training	Current No. of Courses
Resident Training	231
Computer-Based Instruction	35
Correspondence Study	80
On-The-Job Training	28
Out-Of-Agency Training	70
Field-Conducted Training	22
Total	466

Of the 41 AF CBI courses, 23 are operational courses, 9 are demo courses, and the other 9 are refresher courses. Operational courses may include a considerable amount of lab work in addition to CBI. Operational courses are required for certification and include a final test which is scored and recorded on the trainee's permanent record. Demo and refresher courses, on the other hand, are not required for certification. In fact, a student does not receive credit for completing a demo course; however, demo courses are often used as self-study by personnel who want to sit for a bypass test. Refresher courses serve a different purpose altogether. Experienced personnel take refresher courses to review certain material. Such refresher courses include practice tests and upon successful completion of the entire course, the student may print a certificate of completion.

It is important to recognize that CBI, therefore, is only one small, albeit important, part of the overall AF training curriculum. There appears to be a conscientious effort to use a variety of training delivery methods to serve different training needs. The application of advanced technology to maintenance training could allow a new set of courses to be delivered at technician sites to meet the need for refresher/proficiency training.

3.2 APPLICATION OF CBI TO AF MAINTENANCE TROUBLESHOOTING TRAINING

The application of CBI to AF Maintenance troubleshooting training has been somewhat limited. Only one AF CBI course is directed specifically toward diagnostic training. Course 47001 (Troubleshooting Principles) is an operational course that addresses general diagnostic procedures rather than those specific to a particular piece of equipment or system. In addition, most CBI courses which provide training for specific pieces of equipment typically include one or more lessons on diagnosis.

There is a gap, however, in the area of refresher/proficiency training. After initial training is received on a piece of equipment (typically through resident training), a technician returns to the field. Ideally, technicians immediately get reinforcement of the classroom knowledge by applying the classroom knowledge on-the-job; however, this is not always the case. Whenever there are lags between initial learning and application of knowledge or when there are long periods between opportunities to practice skills, attrition of knowledge and skills occurs. Few refresher courses for troubleshooting are currently available; consequently, technicians have little opportunity other than on-the-job training to maintain proficiency.

3.3 EFFECTIVENESS OF AF CBI.

In order to assess the AF CBI courses that are currently available, two visits were made to a regional CBI training center. A Proficiency Development Specialist (PDS) at the center provided assistance by giving a list of courses, logging onto the courses, and answering questions as the content of the courses were reviewed. In addition, one visit was made to the AF Development Unit at the FAA Academy to discuss current and future AF CBI with a small group of CBI programmers and developers. This section first summarizes the status of the present CBI courses. The next section discusses the future plans for AF CBI.

The delivery of nearly all AF CBI is currently administered through the Plato system at regional training centers. The average age of the Plato lessons is greater than 6 years old. The general consensus among those interviewed (including students, instructors, and AF training developers and programmers) was that the Plato system is inadequate for a number of reasons.

Reason 1: Slow network. First, the Plato system resides on a mainframe (CYBER) at Oklahoma City and it is accessed from remote sites with 1200 baud modems. Consequently, the courses delivered through this system have very slow response times and are subject to unavailability whenever some part of the communications network fails.

Reason 2: Unsophisticated courses. A second problem with the Plato system is the nature of the courses delivered by the system. Many of the courses are simple "page-turners" composed primarily of text. A student is constrained to proceed in a predetermined sequence through the material. Users reportedly find this type of instruction uninteresting, presumably due to the lack of engaging interaction. In most cases, this type of CBI training would be more economical (and, given the slowness of the network, more efficient) in book form. In some cases, there is an even greater problem than the simplistic course architecture. During their review of current AF CBI courses, the AF Training Development Unit found that the content of some courses is poorly organized. Such courses are confusing and frustrating for students.

Reason 3: High overhead. A third problem with the Plato system is the extensive use of "introductory" screens. Before reaching any course content, a student must often go through several screens containing such things as logos, directions on using the interface, and objectives. The slow response time of the network makes it a time consuming process to go through all of these screens. To compound this problem, several courses use other media such as text and video. It can be frustrating to go through so many screens only to be told that the content for the course is located off-line.

Reason 4: Unsupported, linear exercises. A fourth problem with the Plato system is the sophistication of the practice exercises. Some exercises are multiple choice questions which were provided as practice for the graded test. No instruction or individualization was given within the linearly ordered questions. If the student answered correctly, positive feedback was given and the next question was presented. If the student answered the question incorrectly, negative feedback was given and the same question was presented. No hint or advice was available to the student.

Some of the newer theory-based courses use a slightly more sophisticated approach. The student is pretested on the material for each lesson. If he/she has already mastered the material, the student will pass the pretest and may then skip to the next pretest. This allows students to move more quickly to the material they don't already know. It was pointed out that the final test for the course is required for all students, even if all pretests are passed.

Reason 5: Limited graphics. A fifth problem with the Plato system is its limited graphics capabilities. The existing system is capable of handling only monochrome line graphics. The test imbedded in such graphics is often quite small and difficult to read. Consequently, the existing system is unable to present the graphic displays necessary to convey important information for diagnostic training and to hold student interest (Johnson, 1987).

3.4 AN OATS SOLUTION?.

Due to frustrating experiences with learning on the Plato system, students reportedly have a very negative attitude about CBI. In an attempt to correct the problems with the Plato system, a new delivery platform has been adopted called Office Automation Training System (OATS). The OATS platform was selected so that computer-delivered instruction can be delivered on a stand-alone system. That is, the courses will be delivered from the local OATS computer without being tied to a remote system through a network. The course material will be stored on CD-ROM and updated CD's will be distributed as needed. For security reasons, however, testing will still be handled over a network.

The AF Training Development Unit has already received positive feedback on the stand-alone course concept. The research team agrees that freeing students from the slow response time of the network is an important step to improving FAA computer-based training. In addition, the AF developers are planning to augment the basic OATS system with special HW and SW to support multi-media learning including audio, video disk, imaging, graphics, and animation capabilities.

Transitioning to the new platform requires translation of existing courses so that they run on the new machines. Rather than "porting" all courses to the new platform, the AF Training Development Unit first reviewed all existing CBI courses for instructional acceptability. Those found to be unacceptable are being discontinued, while the courses which have acceptable content are being upgraded during the conversion to the stand-alone format. The upgrading involves the use of the multi-media capabilities of the OATS platform as well as a break from the simple page-turner format. The AF Training Development Unit at the FAA Academy also indicated their plans to make use of Expert Systems technology for individualized instruction, refresher/proficiency training, and resident courses where appropriate.

Unfortunately, the development of courseware for the OATS platform is not proceeding as planned due to problems with the authoring language. In the past, Tutor, TenCore, and Quest were used to develop courses for the Plato system. With the move to the OATS platform, a new authoring language called Accord has been adopted. There are several problems with the Accord language which are interfering with the development of updated and new courseware. The developers indicated that there is a longer learning curve for getting proficient in using the Accord language compared to TenCore. Reasons given included that there is limited documentation available for Accord and some of the documented syntax did not work as stated. The other complaint was that the resulting programs have slow transitions between screens (approximately 4-5 seconds). As a result, the FAA is now considering a new authoring system (e.g, Authorware Professional or Asymetrix Toolbook).

In summary, the current AF CBI is not addressing the AF troubleshooting training needs. Although AF Training personnel have begun implementing plans to improve the current state of computer delivered instruction, there is room for the addition of an advanced technology training system. Specifically, there is a need for an ITS which provides a supported practice environment for learning how to troubleshoot specific AF equipment.

4. PROTOTYPE ADVANCED TECHNOLOGY TRAINING SYSTEM

The prototype advanced technology training system was developed over a 6-month period. Sections 4.1 discusses the selection of the instructional domain and section 4.2 describes the development and delivery HW and SW. The actual development process involved iterations between knowledge acquisition, design, implementation and evaluation. Section 4.3 focusses on the knowledge acquisition component of the development process. Section 4.4 then describes the components of the final prototype training system.

4.1 SELECTION OF THE INSTRUCTIONAL DOMAIN

The first step in developing a prototype of an advanced technology training system is to identify a piece of AF equipment that is appropriate for this type of training and for which additional training is needed. The goal of this research effort was to develop a prototype training system that could be used immediately by AF technicians in the field.

The initial candidates for the instructional domain suggested by FAA personnel included the Paradyne modem, Air Traffic Control Beacon Interrogator-4 (ATCBI-4) and ATCBI-5, and Common Digitizer. These pieces of AF equipment were suggested because current training was either unavailable or insufficient. After holding discussions with FAA personnel during site visits to the General National Airspace Sector (GNAS) office in Atlanta, GA, and the Air Route Traffic Control Center (ARTCC) in Hampton, GA, the ATCBI-4 was selected as best meeting the criteria for selection shown in table 4. The Paradyne Modem was rejected for the prototype development due to the lack of available troubleshooting expertise. The Common Digitizer was rejected because the training need was not as great as the ATCBI-4. The ATCBI-4 and ATCBI-5 are very similar pieces of equipment. The ATCBI-4 was selected over the ATCBI-5 because of logistics: the research team was located in close proximity to an ATCBI-4 system and expert technicians.

TABLE 4. SELECTION CRITERIA FOR INSTRUCTIONAL DOMAIN

System Characteristics	Technician Needs and Constraints
• It is a complex technical system. • It is not too complex for rapid development of a prototype. • It and its test equipment have a variety of instruments. • It has multiple test points. • It requires a small but critical amount of troubleshooting.	• They need practice to be proficient. • They cannot practice on the real equipment. • They need procedural information to diagnose the system.

4.2 DELIVERY AND DEVELOPMENT HW AND SW

In order for the prototype training system to be of value to the technicians in the field, it had to be developed for an HW delivery system that would be available to the technicians. Given that the FAA had selected OATS machines as the new standard, the prototype advanced technology training system was targeted for delivery on an OATS machine in the Microsoft Windows environment. The prototype requires the following minimal configuration: 386/25 megahertz (MHz) machine, Microsoft Windows 3.0, 4 megabytes (Mb) of memory, video graphics array (VGA) monitor, a run-time version of Asymetrix Toolbook, and a mouse input device.

The initial prototype development, however, began in the DOS environment in order to make use of rapid prototyping tools: Microcomputer Intelligence for Technical Training (MITT) and MITT Writer. Both MITT and MITT Writer run in the DOS environment and use EGA graphics. Figure 3 illustrates the relationship between these two tools. MITT Writer (Wiederholt, 1991) is a development environment that allows users to produce a description of training without the need to write computer code. MITT (Johnson, Norton, Duncan, and Hunt,

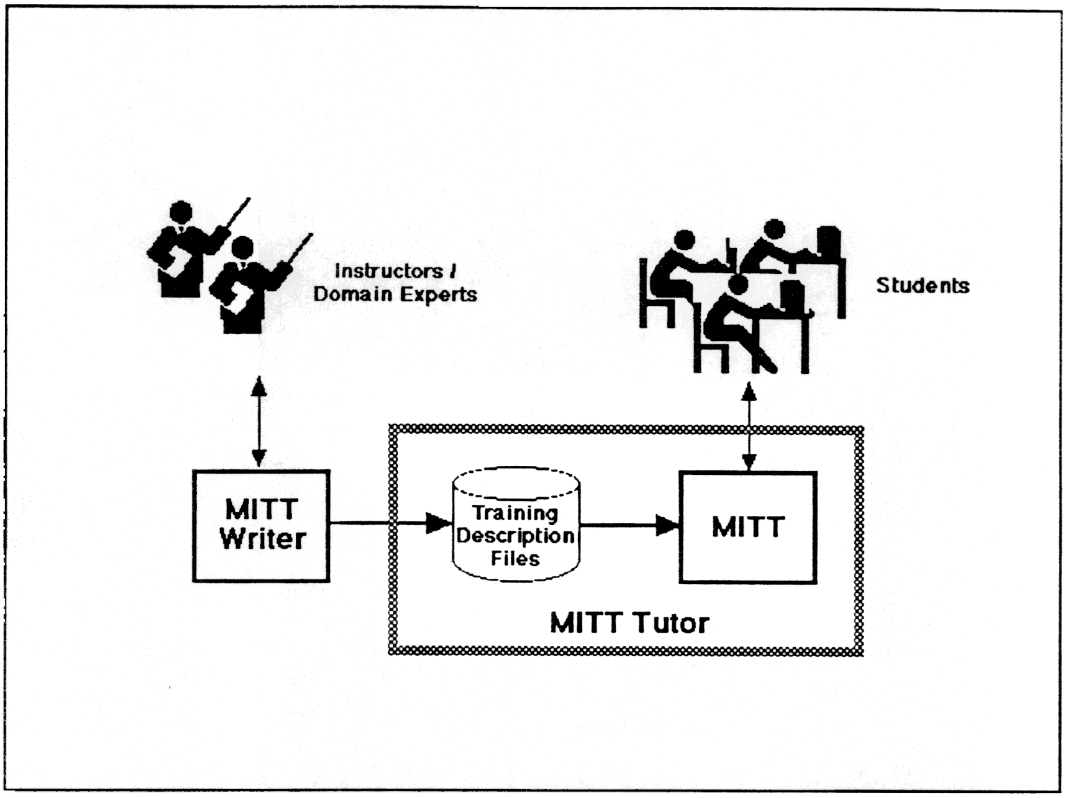

FIGURE 3. RELATIONSHIP BETWEEN MITT AND MITT WRITER

1988; Norton, Wiederholt, and Johnson, 1991) uses the training description files produced by MITT Writer to deliver simulation-oriented troubleshooting training.

In addition to its rapid prototyping capability, the MITT system is an ITS which provides two types of advice: procedural and functional. MITT's functional advice is based on the simulation model which represents the connections between parts. MITT's procedural advice is based on documented troubleshooting procedures and the experience of expert technicians.

Although MITT Writer was designed to aid an instructor or domain expert in developing an MITT tutor, this tool was used by a member of the research team to quickly produce and modify an initial prototype system. The MITT program was then used to run the training system to obtain input and feedback from technicians. Technicians who reviewed the initial prototype system reacted favorably to the MITT approach to troubleshooting training. Thus, the research team decided to capitalize on the MITT technology to develop a new simulation-based ITS that would run in the Windows environment. Asymetrix Toolbook and Borland C++ were used to develop the final prototype.

Figure 4 illustrates the architecture of the final prototype training system. The ATCBI-4 Training Program contains the main training system interface and content. This program then

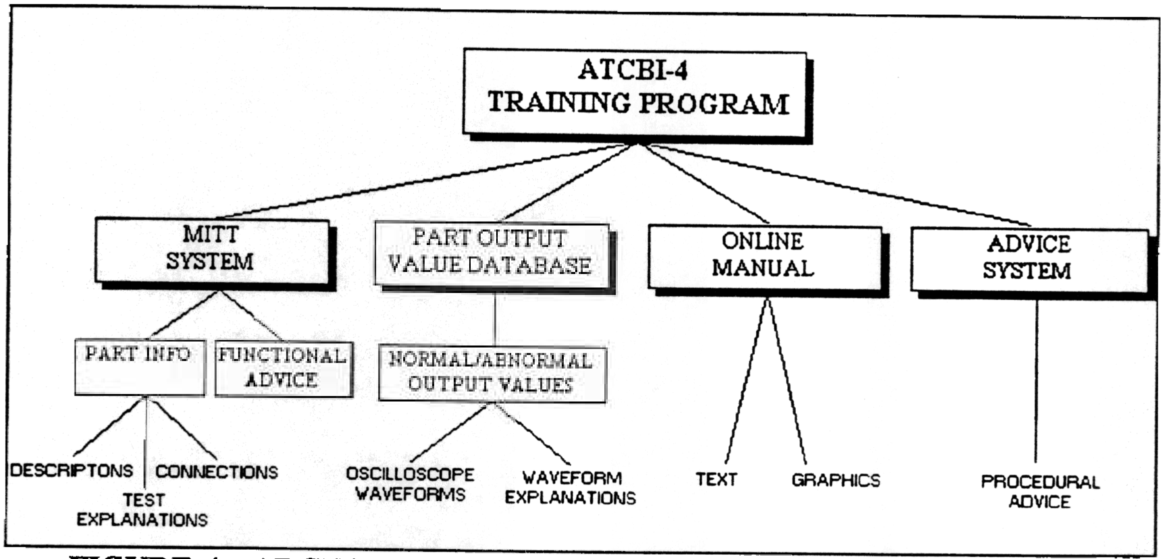

FIGURE 4. ARCHITECTURE OF PROTOTYPE TRAINING SYSTEM

accesses four other specialist programs as needed: the MITT system, the part output value database, the on-line manual, and the advice system

4.3 DESCRIPTION OF THE KNOWLEDGE ACQUISITION PROCESS

The process used to develop the prototype advanced technology training system involved iteration between knowledge acquisition, SW development, and evaluation. The research team worked closely with technicians at the Radar Unit located at GNAS in Atlanta, GA, throughout the development phase.

Initially, a single technician was identified to serve as the ATCBI-4 Subject Matter Expert (SME). One member of the research team worked closely with this technician to gain an understanding of the ATCBI-4 system and the technician's troubleshooting task. The initial knowledge acquisition efforts also relied heavily on existing training materials and the ATCBI-4 manufacturer's manual. The SME, however, is the critical resource in the knowledge acquisition process. This became particularly apparent when the initial SME was sent to the FAA Academy for a 6-week training course. Other technicians were involved in the project at this point; however, similar conflicts continued to occur. The problem was solved by hiring a recently retired ATCBI-4 technician who could devote his full attention to the knowledge acquisition process.

In the remainder of this section, an example of a critical knowledge acquisition task will be used to illustrate the knowledge acquisition process. The example task is the development of a functional flow diagram. A functional flow diagram illustrates the parts of a system and the functional connections between parts. Such diagrams are similar to functional block diagrams and schematics that are common in technical systems. Therefore, the researcher and an experienced ATCBI-4 technician used existing block diagrams and schematics as a starting point for this task. Several iterations were needed to develop the final functional flow diagram used in the prototype.

A key choice in the development of a functional flow diagram is the level of detail that is represented. For example, since the ATCBI-4 system is primarily an electronic system, the parts could be fundamental electronics components (e.g., resistors, capacitors) or entire subsystems (e.g., receiver, transmitter). In general, the answer depends on the level at which troubleshooting takes place. For most malfunctions in the ATCBI-4 system, technicians replace parts at the card level. However, the technicians indicated that they do not solve the troubleshooting task by thinking about flow of signals between cards. Rather, technicians analyze symptoms and make tests based on more abstract functional entities which may include several fundamental components located on different cards. In order to support the troubleshooting process, the parts in the ATCBI-4 functional flow diagram represent this intermediate block level.

During this process, MITT Writer was used to construct and modify the SW representation of the parts and their connections. The resulting SW representation of connections serves as the foundation of the ATCBI-4 simulation and the knowledge base for the functional expert. Therefore, as changes were made, the SME was given printouts of the database (i.e., a listing of parts and their connections) and asked to check the accuracy of the SW representation of the functional flow diagram. A similar process of interviewing, developing, and reviewing was followed throughout the knowledge acquisition process.

4.4 DESCRIPTION OF THE PROTOTYPE.

The prototype investigates the use of advanced technology in proficiency training for AF technicians in the area of troubleshooting. The instructional domain for the prototype (ATCBI-4) is a complex electronics system which is represented at the functional block level rather than at the component level. That is, each functional block represented in the training system is composed of several lower level components in the actual system. The prototype allows technicians to practice troubleshooting on simulated malfunctions (at the functional block level) with the help of an expert advisor. Since there is no single "correct" way to troubleshoot this system, the advisor is primarily passive. However, student actions are tracked to give the proper advice when it is requested. The remainder of this section describes the prototype training system in more detail.

4.4.1 The Four Sections of the Training System.

The prototype training system is divided into four major sections: Introduction to Training, Understand the Simulation, Understand the System, and Practice Problems. Figure 5 shows the main screen of the training system. The four buttons at the bottom of the screen allow the user to access any of the four sections. The Practice Problems section is the primary focus of

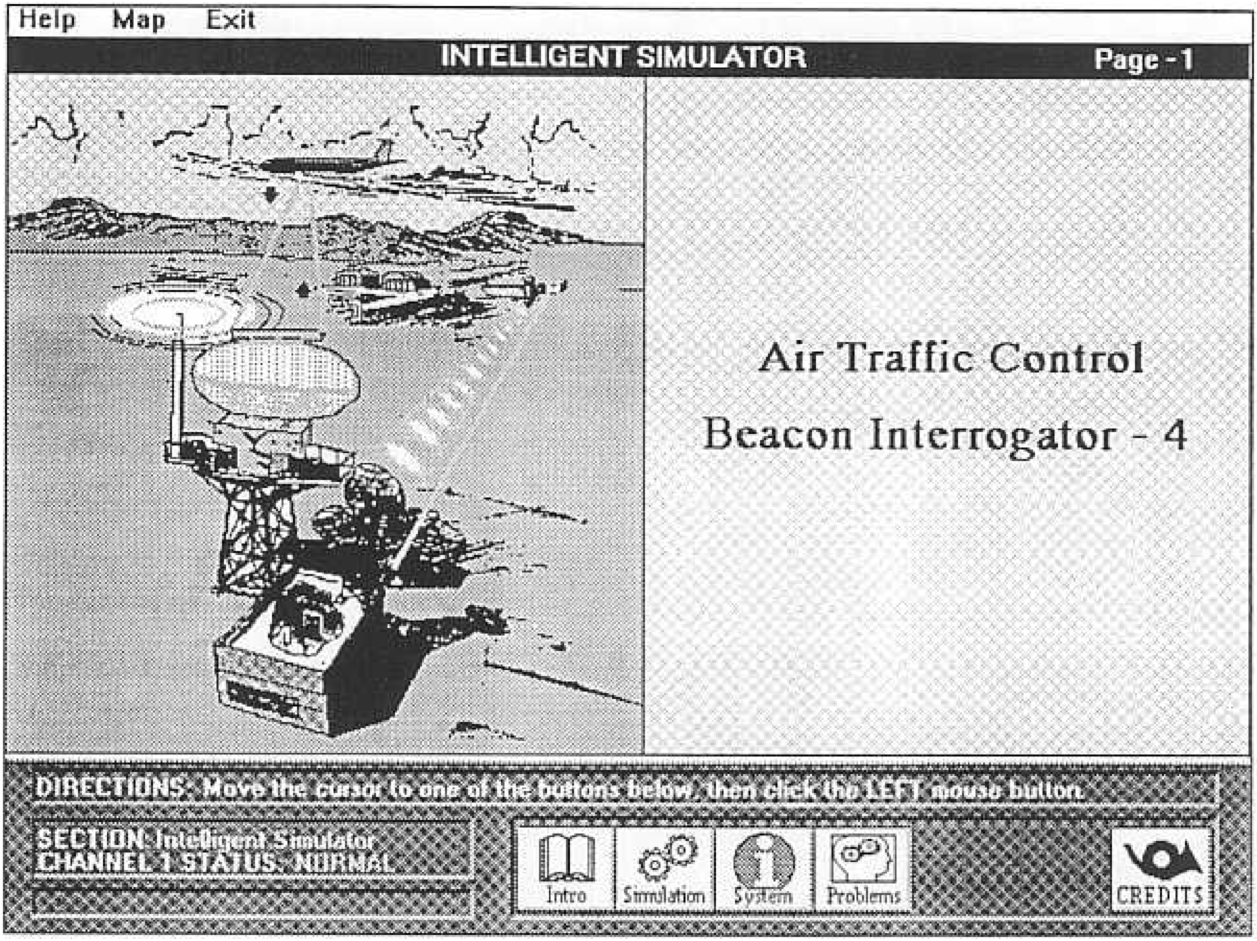

FIGURE 5. MAIN SCREEN OF PROTOTYPE TRAINING SYSTEM

the proficiency training system, while the first three sections provide background and support information. Descriptions of each of the four sections follow.

4.4.1.1 Introduction to Training Section.

The Introduction to Training section orients the new user to the overall training system. It includes a brief explanation of the four different sections and provides exercises for users who are unfamiliar with mouse-driven SW. These exercises allow the novice user to learn how to interact with various direct manipulation objects such as buttons, menus, and dialog boxes. For example, figure 6 shows the screen that instructs the user how to interact with buttons. This section also points out the various help features that are available in the system.

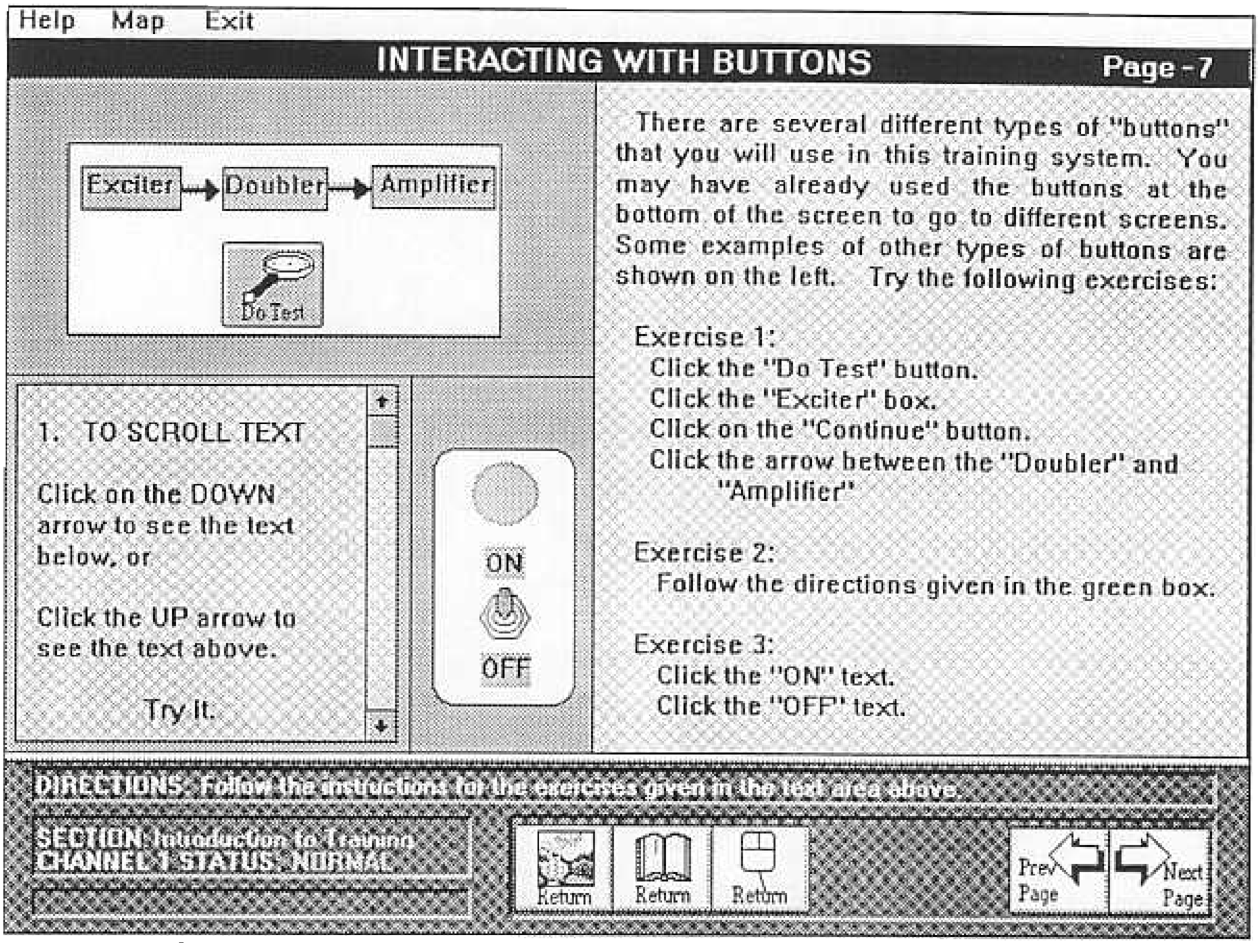

FIGURE 6. EXAMPLE INTRODUCTION TO TRAINING SCREEN

4.4.1.2 Understand the Simulation Section.

The Understand the Simulation section acquaints the new user with the simulation that he will interact with in the Practice Problems section. Before attempting a practice exercise, it is helpful for technicians to know what information is available to them and how to access this information.

The Understand the Simulation section states such fundamentals as the purpose of the simulation, the assumptions that were made in developing the simulation, and how to start and stop the simulation. The technician can also learn about the two types of tests that can be simulated during practice problems (output tests and single part tests) and the different methods for performing each test. In addition, this section explains the two types of advice that are available during a practice problem (functional and procedural advice) and provides interactive examples of each.

This section also allows the technician to become familiar with the simulated displays of the ATCBI-4 and test equipment that they can use during a practice exercise. For example, figure 7 shows the simulated System Monitor Panel of the ATCBI-4. If the technician is unfamiliar with a particular gauge or control, he can click on that control to get a description of it. The technician can also click on control settings to obtain normal meter readings. By accessing such display screens from the Understand the Simulation section, the technician can learn how the real system has been mapped to the simulation.

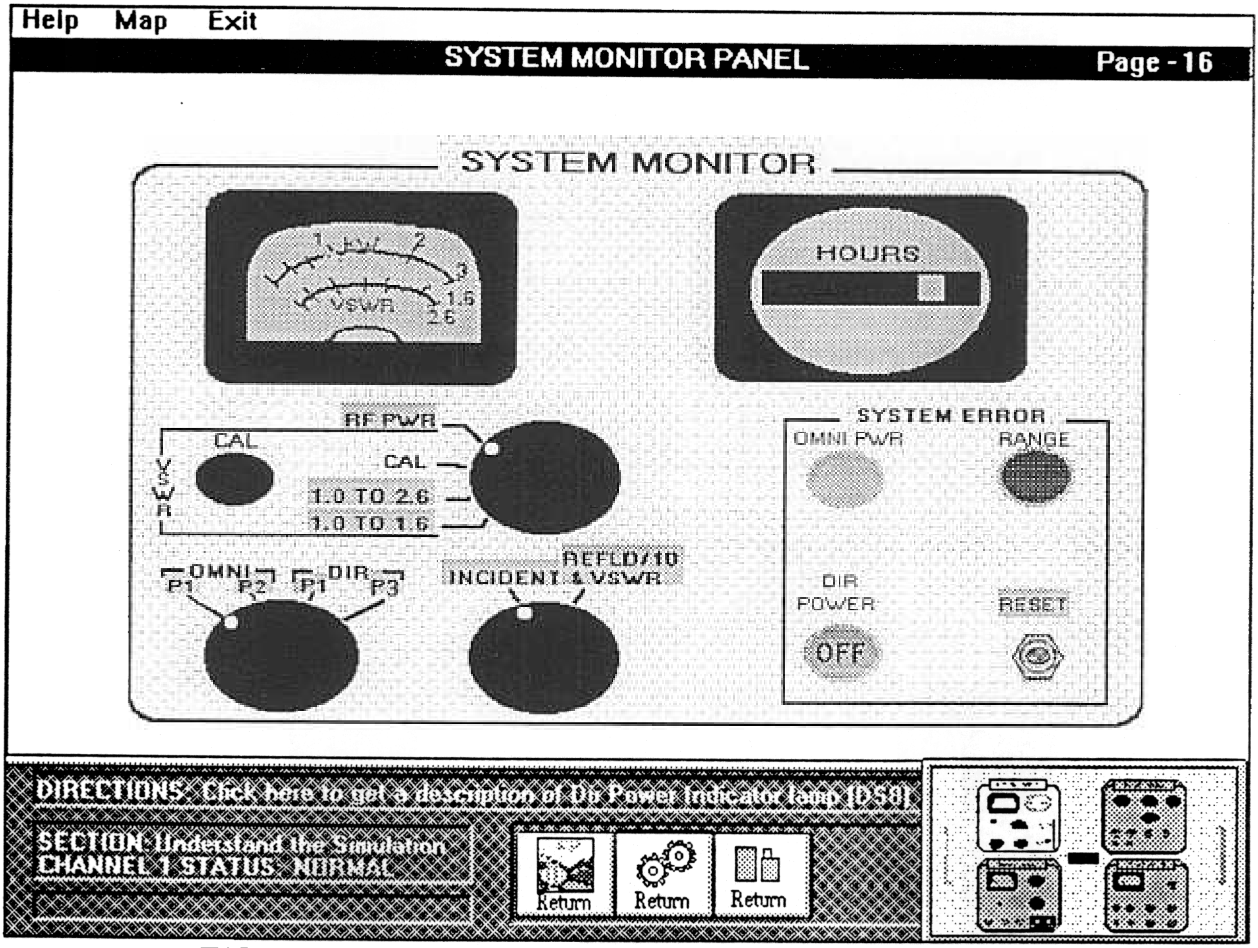

FIGURE 7. EXAMPLE SIMULATION DISPLAY SCREEN

4.4.1.3 Understand the System Section.

The Understand the System section allows technicians to review information about the system equipment that is being simulated and to become acquainted with the reference material that is available on-line. The technician can read descriptions of each part of the equipment represented in the simulation as well as explanations of how to test the part itself and/or its output. The technician can also access various types of reference material such as tables containing standard and tolerance values as well as preventive procedures that are relevant to troubleshooting. The prototype contains a minimal amount of such on-line documentation to illustrate the basic information storage and retrieval capability that will be implemented in a full-scale AF Information System.

In addition, the technician can interact with the schematic-like functional flow diagrams. These diagrams show how the parts of the system are functionally connected to one another. Figure 8 shows the Transmitter Flow Diagram. The buttons at the bottom of this screen allow the technician to perform tests and get part and test information from the diagram. For example, to perform a test on the output of the exciter, the technician would click on the "Do Test" button then click the line that connects the exciter block to the doubler block. A box appears with the results of the test. The colors of the blocks and lines are then updated to reflect the status of parts and outputs that are known as a result of the test. Gray indicates that the status is not known, green indicates that the status is normal, and red indicates that the status is abnormal.

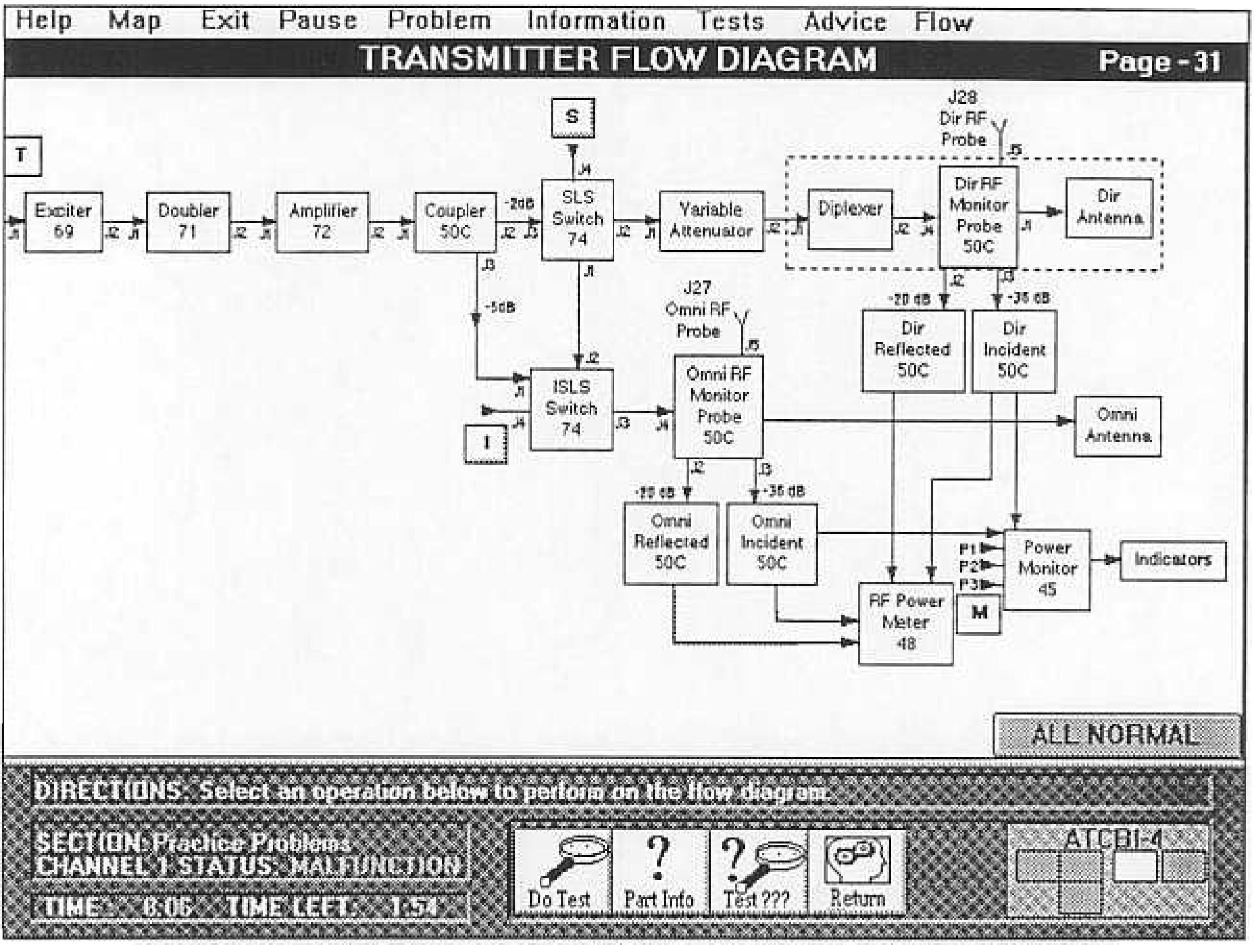

FIGURE 8. EXAMPLE FUNCTIONAL FLOW DIAGRAM SCREEN

In the Understand the System section, all parts and outputs are normal initially so that the technician can review normal system values. If the technician wants to see how the system would change if a certain part has failed, he can select a part to fail in a "What if..." exercise. The technician selects a part to fail by using the functional flow diagram. Once a selection has been made, the diagrams are updated automatically to indicate what outputs are affected by the failed part. Parts and outputs that are normal appear in green, while those that are abnormal are colored red.

4.4.1.4 Practice Problems Section

The Practice Problems section allows the technician to practice the mental skills of troubleshooting with the help of an expert advisor. When the technician starts a practice problem, a scenario is given which states the initial conditions of a problem. Figure 9 shows an example of a problem scenario. The technician is then free to begin troubleshooting. The technician's goal is to identify the malfunctioning component as quickly as possible without making unnecessary tests and without replacing parts that are functioning normally.

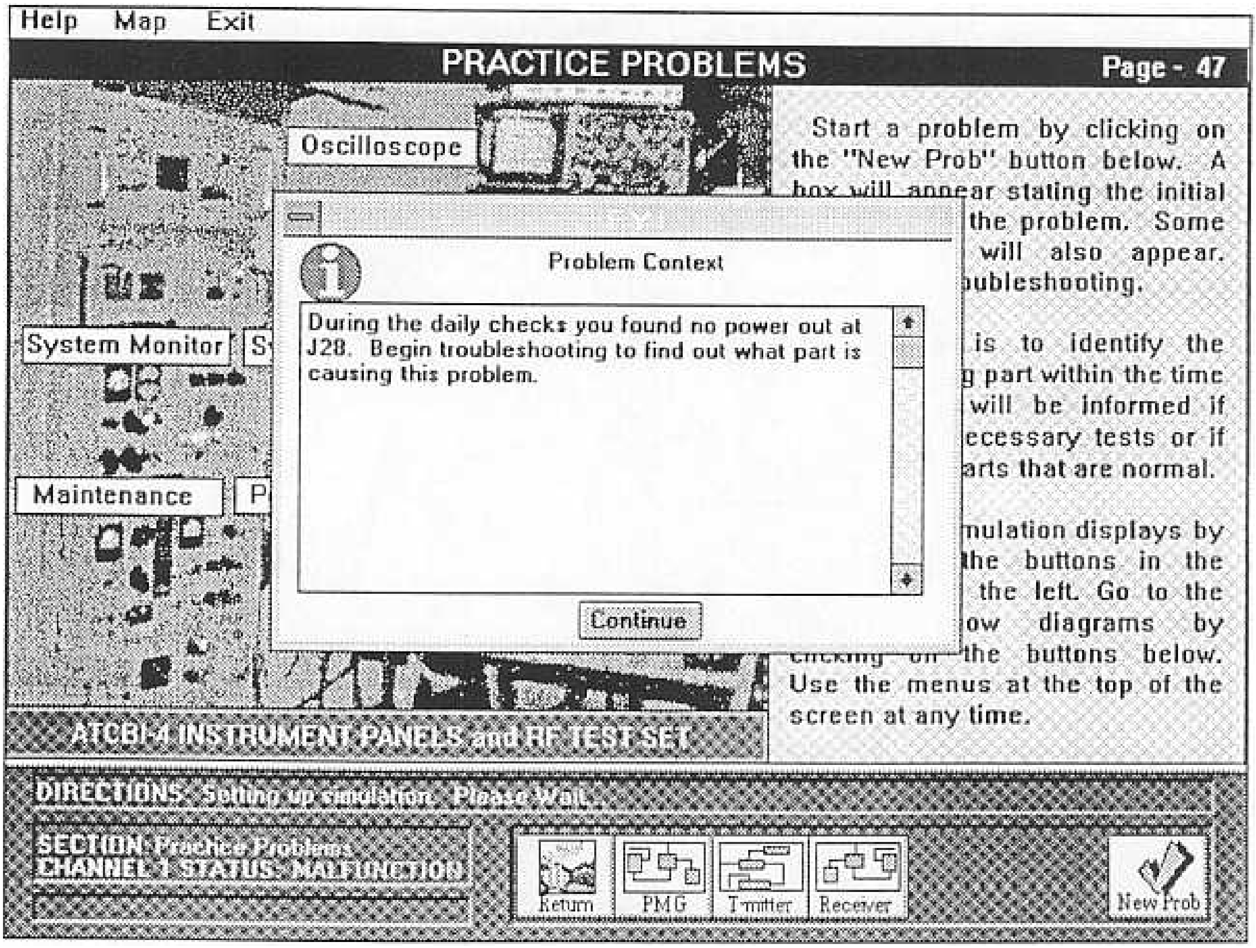

FIGURE 9. EXAMPLE PRACTICE PROBLEM SCENARIO

After reading the problem statement, the technician is free to choose how he wants to solve the problem. In general, the technician can go to the simulation displays or functional flow diagrams and begin choosing tests to perform. There are two levels of information that can be accessed as the result of requesting a test to be performed. Tests performed on the functional flow diagrams or through the use of the Tests menu, however, always state the summarized test result, i.e., whether the part or output is normal or abnormal. By reducing the complexity of the information, the technician can focus on learning more generalized troubleshooting skills.

Technicians who want a higher fidelity simulation may use the simulation displays which provide a more realistic decision environment. On the simulation displays, the test results are given as actual data values which must be interpreted as being normal or abnormal. For example, the oscilloscope simulation display is shown in figure 10. The technician selects a test point (consisting of a card number and pin number) and the waveform is displayed. The technician must then decide if this is normal output for the selected test point. If needed, the technician may request an explanation of the waveform which describes the waveform and states whether it is normal or abnormal.

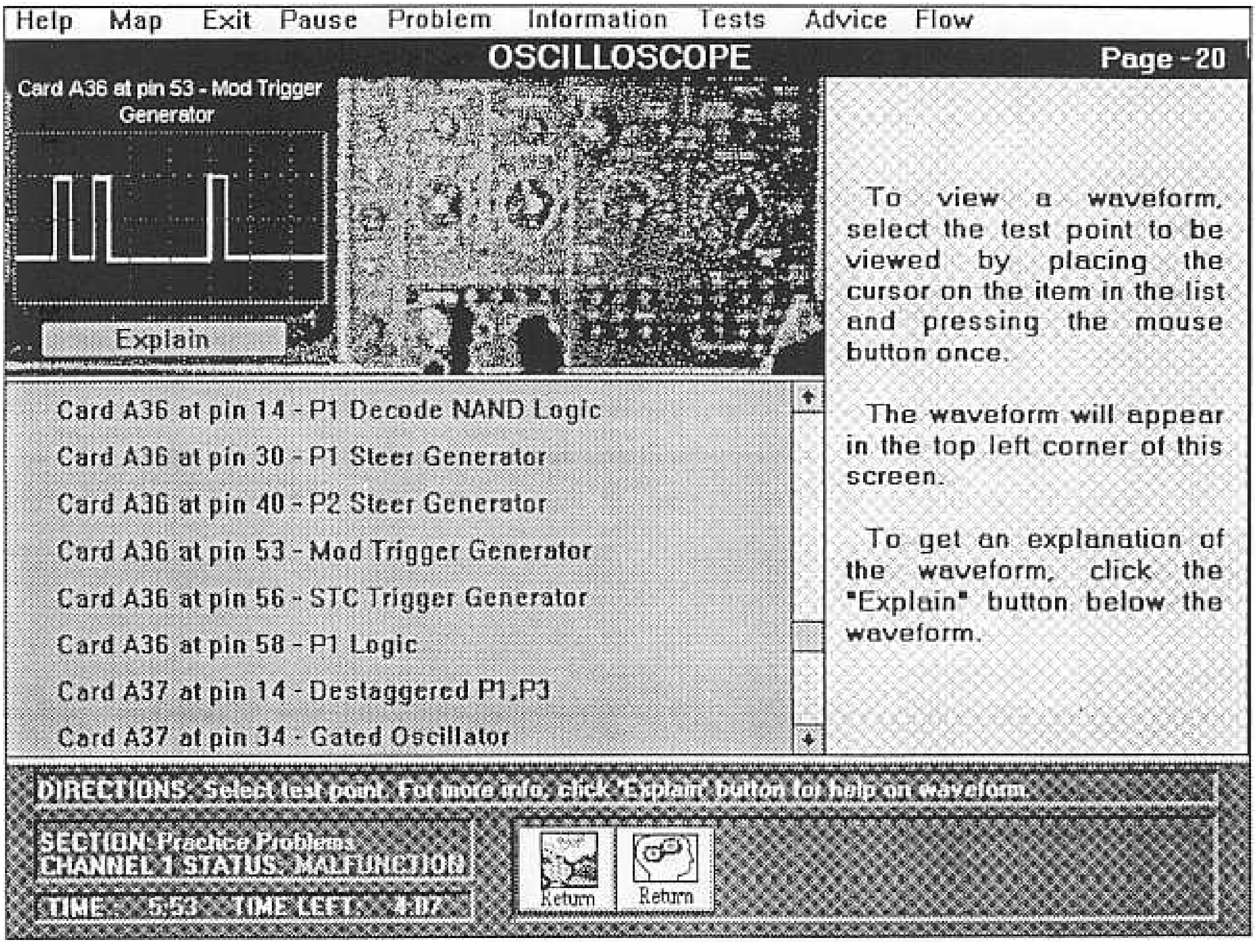

FIGURE 10. EXAMPLE OSCILLOSCOPE TEST

If the technician does not know what tests to perform, a request can be made for either functional or procedural advice. The functional advisor will suggest that the technician perform a test on the part that has the potential for eliminating the most parts from the set of parts that may be causing the malfunction. Functional advice is based on the functional flow connections between parts contained in the simulation of the equipment and logical troubleshooting principles. For example, if a part has bad output, then any part "downstream" of that part cannot be causing the malfunction and can be eliminated from the set of feasible parts. Similarly, if a part has normal output, then any part "upstream" from that part cannot be the malfunctioning part and, therefore, can be eliminated from the set of feasible parts. The functional flow diagrams maintain a visual record of the feasible set by updating the colors of parts and outputs as tests are performed.

The procedural advisor, on the other hand, will suggest a test based on the experience of an expert technician. A recently retired AF technician was consulted to develop the procedural advice for each practice problem. The expert suggested realistic tests for quickly isolating the malfunctioning part. However, it must be emphasized that there is no single "correct" procedure in terms of which part to test in what order. Therefore, the technician is not forced to follow the exact steps suggested by the expert.

There are times when the technician is penalized, however. The system tracks the students actions and provides unsolicited instructional advice when the technician does one of the following: (a) tests a part which is "upstream" from a part that was tested and shown to be normal, (b) tests a part which is "downstream" from a part that was tested and shown to be abnormal, and (c) identifies a normal part as the malfunctioning part. These three actions count as troubleshooting errors that are tallied and reported at the end of a practice problem session. In addition, the system keeps track of how many times the technician replaces a part which is normal. If this action occurs more than a preset number of times, then the system informs the technician that he should use output tests to isolate the fault rather than replacing parts to find the one that is malfunctioning.

4.4.2 Description of the ITS Modules

Section 2.2 presented the generic ITS architecture with its four primary components: the Instructional Environment, the Expert Model, the Student Model, and the Instructional Model. This section will describe these four components as implemented in the prototype training system.

4.4.2.1 The Instructional Environment.

The Instructional Environment is the basic program with which the student interacts to learn. In this system, a simulation is used by the student to practice troubleshooting the ATCBI-4. The main question in the implementation of the simulation is the determination of the appropriate level of simulation fidelity for the learning task.

Simulation fidelity has been defined by Johnson (1984) along two dimensions: physical and psychological. Physical fidelity refers to the degree to which the simulator looks, feels, and functions like the real equipment. Psychological fidelity refers to the degree to which the user of the simulation must call upon the cognitive processes required to troubleshoot the real equipment. The ATCBI-4 training system prototype provides a higher-degree of psychological fidelity than physical fidelity in order to support learning of the cognitive skills of fault isolation in troubleshooting.

The ATCBI-4 simulation provides adequate but limited physical fidelity. The look of the ATCBI-4 equipment is achieved through graphical representations of the system displays and test equipment in the simulator. Such graphics do not provide as high a level of physical fidelity as a full-HW emulation system, however, the graphics are sufficient to attract and hold student interest. The feel of the ATCBI-4 equipment is provided by direct manipulation of some of controls through the use of a mouse. The simulation, however, does not support all of the low level physical skills of troubleshooting (e.g., setting up the oscilloscope to make a test). Finally, the functionality of the ATCBI-4 system is represented by a part simulation.

The part simulation of the ATCBI-4 models the block level components of the equipment and the connections between these parts. Normal and abnormal values are maintained in files indexed to a particular malfunction. Given the malfunctioning component, the simulation automatically computes which parts have normal and which have abnormal output. Although this level of simulation was satisfactory for the prototype system, deeper simulation is being considered for future work. Although deeper simulation requires more work initially to develop and verify the models which transform inputs to outputs, this effort earns savings when adding new troubleshooting problems.

Although physical fidelity is important, the focus in this work was on developing the psychological fidelity of the ATCBI-4 simulation. Psychological fidelity is achieved by providing the information resources that are available to the technician during fault isolation in troubleshooting. This information begins with a realistic problem scenario. The statement of the problems should map to realistic situations encountered by the technician.

Psychological fidelity is also important during fault isolation. Access to test information and reference information is needed to support the cognitive aspects of the troubleshooting process. Throughout the simulated fault isolation process, technicians choose what tests to perform and what information to gather as they would in the real system. They also interpret what to do next based on the results of each test. However, since this is a learning environment, help is available to the technician to support selection of tests and interpretation of test results. Advice about what tests to perform and feedback for student actions relies on the expert, student, and instructional modules.

4.4.2.2 The Expert Model.

The Expert Model in the ATCBI-4 encodes two types of expertise: functional and procedural. Both types of advice were discussed from a user's point-of-view in section 4.4.1.4. This section will focus on the implementation of the two types of advice.

The functional expert is closely coupled to the simulation. The functional expert uses the simulation's representation of part connections to implement a half-split type algorithm. For each problem, the functional expert maintains a dynamic list of feasible parts (i.e., parts which may be causing the malfunction). Initially, all parts are in the feasible set. Each time a test is made, the functional expert updates the list of feasible parts, based on the functional connections between the parts and the status of the part for the current malfunction. For example, if the output of part A is tested and shown to be normal, then the functional expert would eliminate all parts that feed part A from the list of feasible parts, since these parts cannot be malfunctioning. When a technician asks for functional advice, the functional advisor applies a half-split strategy to the feasible set, i.e., it suggests the technician test the output of the part which has the potential for eliminating the most parts from the feasible set.

The functional expert is essentially a Baysian problem solver, achieving maximum information gain per action. Because the functional expert is context-free (i.e., it has no knowledge or understanding of the technical domain), it always has an answer, based only on the functional connectivity among the components. Research in the late 70's and throughout the 80's demonstrated that the functional/logical approach to diagnostic training is effective. The approach was shown to be effective in such training domains as aircraft mechanics (Johnson and Rouse, 1982), nuclear power plant technicians (Johnson, Maddox, and Kiel, 1984), U.S. Army electronics troubleshooting (Johnson and Fath, 1984), NASA space shuttle diagnosis (Johnson, et al., 1988), and in other domains.

The procedural expert is a rule-based Expert System. The procedural models the knowledge of expert troubleshooters in the form of if-then type rules. The "if" part of each rule contains conditions that must be met for the advice to apply, such as "If part J is in the feasible set and the output of part K has not been tested." The "then" part of each rule contains the advice that is given and explains what test to make next. In the prototype system, a procedure is encoded for each problem. When a technician requests procedural advice, the procedural expert looks for a match in the condition of each rule of the procedure in reverse order, so that the most appropriate test is suggested.

4.4.2.3 The Student Model.

The Student Model of the ATCBI-4 prototype tracks student actions in the simulation. The student actions that are tracked include: tests performed (single part and output) and requests for advice (functional and procedural). The student model also maintains a count of the student errors that are detected by the instructional model (described in the next section). At the end of a problem, the student model is summarized with the following information: how many times advice was used, how many errors were made, how many tests were performed, and the time it took for the student to solve the problem. A performance index is also given based on this data.

The Student Model described above is a "within" problem model. That is, the model tracks the performance of a student within a single problem. As more problems are added to the training system during Phase II of this research, the student model can be extended to include an "overall" student model. That is, a model that records the types of problems that the technician has attempted and how well the student has performed on each type of problem. Such a model could then be used to support intelligent problem selection, rather than random or linear problem selection.

4.4.2.4 The Instructional Model.

The Instructional Model in the ATCBI-4 prototype detects errors in student actions by comparing student actions to the functional expert model. Such errors are based on a few general rules for correct troubleshooting behavior. For example, if a part has been eliminated from the set of feasible parts by previous student actions, then it is an error for the technician to perform a test of this part. Finally, the instructional model checks for unrelated tests of outputs or parts. For example, if the technician performs a test of a part whose output does not reach any part which is known to have abnormal output, the test is considered an error.

It should be noted that the Instructional Model in the ATCBI-4 prototype focuses on logical rather than procedural troubleshooting errors. The instructional model does not compare the technicians actions to the steps of the procedural expert because there is no single "correct" way to troubleshoot the system. However, the instructional model can be extended in Phase II to reinforce the expert procedures by providing the step by step procedure for review by the technician at the completion of each problem.

In addition, the instructional model can be extended to include a taxonomy of the types of problems that are encountered in troubleshooting. Such a taxonomy provides the curriculum that is to be taught by the training system. Furthermore, individual problems can be rated in terms of difficulty. As alluded to in the section on student modeling, such indexing can be used as the basis for selecting the most appropriate problem for the current student.

4.5 DISCUSSION OF THE PRELIMINARY EVALUATION.

An informal preliminary evaluation was conducted with the prototype SW. Three technicians were observed while interacting with the prototype training system during approximately 1-hour sessions. None of the technicians had used the prototype prior to this session.

Each session began with the first screen of the training system already displayed. The developers informed the technician that the purpose of the session was to interact with the training system to determine what they like and dislike about the system. Each technician was also informed that there would be an evaluation sheet provided at the end of the session to solicit such feedback. A copy of the evaluation sheet is included in the appendix.

In general, the three technicians were able to use the system with little input from the observers. No major errors were encountered; however, minor changes to the interface were made in response to user comments. The technicians all gave positive verbal comments about the system and each was able to successfully complete a practice troubleshooting problem. Two of the three technicians indicated that they would use this system for proficiency training. (The technician
who indicated that he would not use this system is a supervisor and is no longer responsible for troubleshooting the ATCBI-4 equipment.)

5. PLANS FOR PHASE II.

In the second phase of this research, the prototype system will be extended into a complete proficiency training system for troubleshooting the ATCBI-4. There are four major tasks involved in this effort. First, input will be obtained from the AF Development Unit and AF technicians to guide development of the complete training system. Based on this input, changes will be made to extend the Instructional Environment, Student Model, Instructor Model, and/or the Expert Model. Third, knowledge engineering work will continue in order to extend the set of simulated practice problems to include approximately 10 to 12 malfunctions. Finally, the knowledge base of domain specific data will be restructured to improve the access time. The completed ATCBI-4 training system will be installed at the GNAS radar unit in Atlanta, GA, and will be made available for distribution to other FAA radar sites.

Upon completion and review of the final ATCBI-4 training system, work will begin on a development system for authoring additional AF Maintenance ITS's. The research team will work with personnel at the FAA Academy to develop a functional specification to meet the needs and desires of training development personnel. A demonstration development system will be developed to provide a concrete basis for the discussion.

The final activity of Phase II will be the development of a plan and preliminary specification for an advanced technology AF Information System. The AF Information System will integrate three components into one system: training, job-aiding, and information storage and retrieval. The training system completed in this phase will serve as the model for the training component of the AF Information System. The research plan will detail how the knowledge base of the training system will be extended to support real-time job aiding. In addition, the plan will describe the development plan for the development of the on-line documentation system.

6. CONCLUSIONS.

This research has: (a) investigated the current status of Airway Facilities (AF) training and found that simulation, Expert System, and Intelligent Tutoring System (ITS) technology has not been used in the computer based training that is currently available to AF technicians, and (b) produced a prototype advanced technology proficiency training system that uses simulation, Expert System, and ITS software (SW) technology and which is delivered on affordable hardware (HW). The work in future phases will seek to: (a) develop an authoring system to permit non-programs to build similar types of training systems, and (b) to extend the prototype system into an AF Information System, integrating the training system with real-time job aiding and information retrieval.

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APPENDIX A

EVALUATION FORM FOR ATCBI-4 PROTOTYPE

Rate the following on a scale of 1 to 5 where 1 is the lowest rating and 5 is the highest rating.
Your Background:

1 Familiarity with the ATCBI-4 system.
(1 = have not worked on it in past 2 years+ 5 = work with it daily)
Experience using mouse-driven software.
(1 = no experience 5 = extensive experience)

ATCBI-4 Prototype Tutor

___ 1. The usefulness of the training system for refresher/proficiency training.
(1 = not very useful 5= very useful)

___ 2. The "user friendliness" of the system.
(1 = frustrating to use 5 = easy to use)

_ 3. The accuracy of the simulation information.
(1 = not very accurate 5 = very accurate)

_ 4. The likelihood you would use this training system if it were available.
(1 = never 5 = frequently)

COMMENTS

In the space provided below, indicate any additional comments you have about the four sections of the training system, including suggestions for improvement.

Comments about Introduction to Training

Comments about Understand the Simulation

Comments about Understand the System

Comments about Practice Problems

Miscellaneous Comments (on back)

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