FROM AN INTELLIGENT JOB AID TO AN INTELLIGENT-COMPUTER-AIDED-TRAINING SYSTEM: TRAINING APPLICATIONS OF THE INTEGRATED MAINTENANCE INFORMATION SYSTEM (IMIS)

Leo Gugerty, Kimberly Hicks, William Walsh
Mei Technology Corporation
San Antonio, Texas

ABSTRACT

The goal of the project described here is to investigate the training uses of the Integrated Maintenance Information System (IMIS). IMIS is being developed by the Air Force's Armstrong Laboratory as a job aid (using automated tech-order data) for aircraft maintenance technicians who are performing duties on the flightline. This project involves conducting an analysis of current Air Force maintenance training practices, developing a prototype of how IMIS can be used in Air Force training at Technical Training Centers and operational bases, and demonstrating this prototype in a realistic training situation.

In this paper, we first describe the IMIS system and briefly report the results of our analysis of current Air Force maintenance training practices. Then, we suggest a general procedure for planning how to add training capabilities to job aids, and describe how we followed this procedure in planning the IMIS training system. Finally, the prototype IMIS training system is described.

The most effective use of IMIS in training would be as an intelligent simulation environment. In terms of the content of training, the prototype we are developing will explicitly train novice technicians (skill level 3) in some of the key strategies and knowledge used by expert aircraft troubleshooters. In terms of training methods, the prototype will follow cognitive-apprenticeship-training principles and will be designed to stimulate collaborative learning and discussion. It will include some aspects of an intelligent tutoring system, such as limited student modeling and adaptive instruction.

ABOUT THE AUTHORS

Dr. Leo Gugerty is a cognitive psychologist in the Training Technology Division of Mei Technology Corporation. His research focuses on complex problem-solving skills (such as troubleshooting) and effective interventions to train these skills. He has a Ph.D. in Cognitive/Experimental Psychology from the University of Michigan, Ann Arbor, and has held research positions at Educational Testing Service, Lockheed Engineering and Sciences Co., and the University of Houston.

Kimberly Hicks is an Industrial Psychology Specialist in the Training Technology Division of Mei Technology Corporation. Her work is concentrated in the areas of training systems analysis, and survey development and analysis. She has an M.A. in Industrial Psychology from St. Mary's University, San Antonio, TX.

William J. Walsh has been involved in the design and development of training systems, and researching training technology issues for over 15 years. He has worked on and managed programs involving various implementations of training technology, including computer-based training, multimedia applications, intelligent computer-assisted training, simulations of maintenance and troubleshooting, and distance learning among others. Recently his concentration has been on technological applications to reduce instructional development time and increase instructional quality.

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THE IMIS JOB AID

One of the main purposes of IMIS is to integrate the wide range of information needed to perform maintenance activities and give technicians easy access to this information through a single system. IMIS is intended to integrate the following kinds of information:

- Maintenance Procedures, i.e., Technical orders (TOs)
- *Diagnostic information*
- Flight data
- *Aircraft historical data*
- Supply and management data
- Training data

Currently, only the technical orders and diagnostic information are available in the IMIS job-aid prototype. The IMIS prototype is being developed for the F-16 aircraft.

In its present configuration, the IMIS hardware consists of the Maintenance Workstation, the Portable Maintenance Aid (PMA), and the Aircraft Interface Panel. The workstation is used during the early stages of maintenance to help debrief the pilot, analyze flight and historical data, schedule the maintenance activity, and assemble a set of TOs and other information that can assist the technician during troubleshooting and repair. A portion of this information is downloaded into a memory module which is inserted into the PMA. The PMA is a rugged computer about the size of a commercial laptop. The technician takes the PMA to the flightline and hooks it up to the plane with the Aircraft Interface Panel. During troubleshooting and repair, the technician has access, via the PMA, to any TOs that are needed and to additional advice from IMIS's Diagnostic Module. The PMA can also access information from the aircraft, such as built-in-test data. The technician can use the PMA to order parts and to issue maintenance status reports via a radio link to the workstation.

One of the main components of IMIS that can be used in training is the Diagnostic Module (Cooke, Maiorana, Myers & Jernigan, 1991). This *software module provides expert troubleshooting* advice to the technician, based on a database of common aircraft symptoms, the faults that could cause specific symptoms, component failure rates, and the expected results of tests and replacements. These data are used by the Diagnostic Module to provide advice during troubleshooting beyond that contained in the TOs. The database of symptoms, faults, failure rates, and test results used by the Diagnostic Module is called the Content Data Model (CDM). The CDM also contains electronic copies of the TOs needed for F-16 maintenance.

CURRENT MAINTENANCE TRAINING

In analyzing current Air Force maintenance training practices, we conducted structured interviews at Technical Training Center, Field Training Detachment, Logistics Support Training, and on-the-job training sites at Kelly AFB, TX, Hill AFB, UT, and Lowry AFB, CO. The interview data suggest that maintenance technicians especially need training in the problem-solving skills necessary to handle troubleshooting problems that are not solvable by standardized procedures (e.g., TOs). Since we felt that an effective training use of IMIS is as an intelligent maintenance simulator, we noted current uses of maintenance simulators at the bases. Maintenance simulators (part-task trainers) are currently used in the Technical Training Center and Field Training Detachment classrooms. However, there are a number of problems with their use. First, individual student access to the simulators is limited. Second, the existing simulators are hard to update and may not be used at all when they become outdated. Third, the simulators only give students problems requiring routine use of the TOs, despite the fact that technicians often face problems on the job that require knowledge beyond the TOs.

ADDING TRAINING CAPABILITIES TO JOB AIDS

Adding a training capability to a job aid presents a number of opportunities and problems that do not exist when a training system is developed from scratch. The main advantage of starting with an existing job aid lies in the often extensive job knowledge encoded in the job aid. Some of this knowledge can potentially be used in the training system. If it can, this will save some of the effort of eliciting job knowledge from human experts and encoding this in a representation that can be used by a computer. However, whether the job knowledge in a job aid can be used in a training system depends on how this knowledge is encoded or represented. If the job knowledge is represented in a form similar to the way humans think about this kind of knowledge, then the knowledge will be relatively easy to use for training. Systems with human-like representation of expert knowledge have been called *glass-box* expert systems (Burton & Brown, 1982, Anderson, 1988). The problem is that most job aids contain *black-box*, rather than glass-box, expert knowledge. That is, they represent and process job knowledge in a form very different from human experts. If a job aid uses a black-box knowledge representation, the job knowledge is much less useful in training.

Based on these considerations, we suggest the following process for planning how to add training capabilities to job aids:

1. Conduct a cognitive task analysis of the task to be trained. This will identify the subtasks necessary to perform a task at an expert level, and the knowledge and cognitive processes needed for each subtask (Hall, Gott & Pokorny, 1989).
2. Compare the knowledge representations and algorithms used in the job aid with those used by human experts. This will reveal which types of expert knowledge and cognitive processes can be trained using the existing job aid knowledge representations, and which will require more extensive development.
3. Plan which types of task knowledge and cognitive processes will be conveyed by the training system, and what training methods will be used to convey them.

Since job aids often reduce the need for training, it may seem incongruous to add training capabilities to job aids. However, for difficult tasks like maintenance, job aids will never eliminate the need for training. For example, IMIS will not be able to solve all troubleshooting problems. Given the continued need for training, integrating training and job aiding capabilities has several advantages: 1) using the intelligence of the job aid in training, 2) allowing the job aid to help train users so that they can handle the problems that the job aid cannot, and 3) providing realistic training with the job aid that is more likely

Table 1. Knowledge Used by Human Troubleshooters and IMIS

Knowledge Used by Expert Troubleshooters			Extent of Use of Human Troubleshooting Knowledge by IMIS
Knowledge Category	**Knowledge Type**	**Description**	
Declarative	Mental Models	"How-it-works" knowledge pertaining to system structure (topography), function, and behavior.	Limited
	Symptom-fault Associations	Associations between symptoms and faults. Fault probabilities.	Extensive
Procedural (Cognitive Processes)	Procedures	Step-by-step information about how to perform specific actions	Extensive
	Strategies	More general processes that coordinate the use of procedures, using mental models or symptom-fault associations.	Uses key strategies
	Coordination Processes	Very general, metacognitive processes that involve activities such as strategy selection.	Moderate

to be accepted in on-the-job training environments than stand-alone computer-based training.

CREATING AN IMIS-BASED TRAINER

Cognitive Task Analysis (Step 1)

In the following, we describe how we followed this process in the case of the IMIS job aid. Our task analysis focused on the knowledge needed for troubleshooting, as our analysis of current maintenance training suggested that troubleshooting is a high-priority Air Force training need. Our analysis of expert human troubleshooting was based on a large number of studies of troubleshooters (e.g., Rasmussen, 1981, Gott, 1988, Lesgold & Lajoie, 1991). In Table 1, we describe the types of knowledge used by expert troubleshooters (Step 1), and evaluate the extent to which IMIS uses each of these types of knowledge (Step 2).

Table 1 lists the key knowledge required for expert troubleshooting under two categories, declarative (or factual) knowledge and procedural (or skill) knowledge. The procedural knowledge (or cognitive processes) is hierarchical in nature, with the coordination processes being the most general. These processes organize the use of strategies, which in turn control the use of the more specific procedures. There is no hierarchical relationship between the two types of declarative knowledge, mental-model and symptom-fault-association knowledge. Rather, each of these types of knowledge is used by different troubleshooting strategies, as is described below.

Mental model knowledge, in the context of troubleshooting, is knowledge of how the device or system works. It includes knowledge of the internal structure (or topography) of the system, the functions of system components, and the states (or behavior) of the system. A mental model can be used to answer what-if questions about the system, such as how the failure of a particular component will affect the behavior of the rest of the system. Symptom-fault associations are remembered associations between specific symptoms (improper system behaviors) and the internal system faults that usually cause them. When your mechanic diagnoses your car problem instantly after listening to the engine and looking at the color of the exhaust smoke, he or she is using symptom-fault associations.

Procedures knowledge consists of step-by-step information about how to perform specific actions, such as testing resistance with a multimeter. Strategies are more general processes that help organize technicians' search for the faulty component. There are two main kinds of troubleshooting strategies (Rasmussen, 1981). The first involves using symptom-fault-association knowledge to recall the fault that was found to cause a symptom in the past, and then testing for this fault. The second involves using mental-model knowledge. An example of the second type of strategy is elimination, in which the technician uses information about correct system behaviors and knowledge of system function and topography to eliminate from consideration components that can be inferred to be working. So, if your car will not start but your lights work, you can eliminate the battery as a possible cause of the problem.

Coordination processes involve metacognitive thinking, in which technicians monitor how well their strategies are meeting the various constraints of the problem (e.g., finding the fault, having a plane ready on time) and change strategies accordingly. A technician is using coordination processes when he or she decides, because of time constraints, to stop trying to isolate (locate) a specific fault and instead make a costly component replacement that will fix the problem quickly.

Comparing IMIS to the Task Analysis (Step 2)

The next step is to see how well IMIS's knowledge and algorithms match up with those used by human experts. IMIS's Diagnostic Module uses extensive symptom-fault-association and procedures knowledge. The data in the CDM on symptoms, faults, failure rates, and test and replacement results are equivalent to symptom-fault associations. The CDM data on TOs are examples of procedures knowledge.

In addition, the Diagnostic Module uses two troubleshooting strategies that are commonly used by expert technicians. The first of these is elimination. Recall that in this strategy, all components that are spanned by (i.e., lead into) a troubleshooting test yielding a successful result (a pass) are eliminated from the set of potentially faulty components. During troubleshooting, the PMA screen shows a list of tests recommended by the Diagnostic Module and a block diagram of the faulty aircraft subsystem. Different kinds of shading are used to indicate visually which components are spanned by the most highly recommended test, and which components have been eliminated based on a test result.

The Diagnostic Module also uses a version of half split (or binary search), a strategy that is used by human experts. A typical use of half split by a person employs topographic mental-model knowledge. For example, if the person knows that the current set of potentially faulty components is connected in a chain, then the half-split strategy would involve testing a component in the middle of the chain. This would ensure that, whether the test passes or fails, half of the components can be eliminated. However, the tests recommended by the Diagnostic Module do not always conform to the strict half-split strategy, because the Diagnostic Module considers other information in addition to the half-split strategy when choosing tests, information such as component failure rates and the time to perform tests and replacements.

In terms of coordination processes, the Diagnostic Module considers some of the same kinds of information that a person would in planning how to attack a troubleshooting problem and deciding what strategies to use. This includes information such as the time to perform tests and replacements, and parts availability. However, the Diagnostic Module's overall coordination processes are much different than humans. The Diagnostic Module algorithm uses an exhaustive-search approach, evaluating every fault (in its database) that could possibly cause the current symptoms, and every test that could possibly give information about the most likely fault. These faults and tests are evaluated via extensive numerical computations that are not used by human troubleshooters.

Another key difference between the Diagnostic Module and human troubleshooters is that the Diagnostic Module uses very little mental-model knowledge, that is, very little knowledge of the system functions and topography, in its reasoning. One kind of mental-model knowledge that is used by the Diagnostic Module is knowledge of the components spanned by different troubleshooting tests. This knowledge is used by the elimination and half-split strategies. Other than this, the Diagnostic Module relies primarily on symptom-fault association knowledge, rather than mental-model knowledge.

These similarities and differences between the human and the Diagnostic Module's approach to troubleshooting will affect how IMIS can be used as an *intelligent* training system. For example, a key feature of an intelligent training system is its ability to explain its reasoning processes to students. A system's explanation capabilities will be more effective to the extent that its reasoning processes approximate those of a human expert (Anderson, 1988). The above analysis shows that, although the Diagnostic Module was not intended to simulate human troubleshooting processes, its knowledge and reasoning processes overlap considerably with those used by expert troubleshooters. The Diagnostic Module is somewhere between a *black-box* and a *glass-box* expert. In its current capacity as a job aid, the Diagnostic Module can explain its recommended tests and replacements using the following information from the CDM: the expected results of tests and replacements (symptom-fault association knowledge) and the time for tests and replacements. It would be easy for the Diagnostic Module to construct explanations based on other symptom-fault-association knowledge and troubleshooting strategies, and more difficult (though not impossible) to construct human-like explanations in term of mental-model knowledge and coordination processes.

Planning the Content and Methods of Training (Step 3)

The cognitive task analysis (Step 1) specifies the content that must be trained. In addition, comparing the job aid's capabilities to the cognitive task analysis (Step 2) gives an indication of how easy it would be to train different aspects of this content using the knowledge already in the job aid. The next step is to plan how the job aid will be used in training the content knowledge identified in the task analysis. This planning involves making choices about the instructional and assessment methods that will be used.

In the IMIS training system, we decided to use the methods of *cognitive apprenticeship training*: practice on realistic problems, coaching, fading, and collaborative learning (Collins, Brown & Newman, 1989). These methods, which will be described below, fit well with the apprenticeship methods used in on-the-job maintenance training, and have been found to be effective in teaching complex skills such as troubleshooting (Lajoie & Lesgold, 1989). Modeling IMIS's training on current on-the-job training practices will increase the likelihood of its being accepted in the flightline environment, both as a job aid and as a trainer.

IMIS can be used at each phase of the instructional process, including instructional design, instructional delivery, performance assessment, course management, and recordkeeping. In this paper, we will focus on the instruction and assessment phases.

Instructional Uses

We feel that the most effective instructional use of IMIS is as a simulator, and so we have concentrated on this use in designing the training prototype. There are two reasons for this focus. First, as a job aid, IMIS provides an interface (the PMA) that coordinates the entire maintenance process for the technician. Therefore, it would be very easy to implement realistic simulations using the PMA. Second, we feel that an IMIS simulator could be of significant help in training the most difficult skills technicians have to learn -- the problem-solving skills required for expert troubleshooting.

The apprenticeship-training literature suggests that coached practice is essential for learning complex problem-solving skills. OJT supervisors we interviewed also stressed the importance of practice in training maintenance skills. However, our data shows that in Technical Training Centers and Field Training Detachments, students have very little chance to practice their skills on aircraft or simulators. As we will describe below, an IMIS simulator can provide extensive coached practice on troubleshooting problems, thus meeting a crucial training need.

Technicians also need training in many procedures that do not involve complex problem-solving. Furthermore, some of these procedures (e.g., removing and replacing components, using a multimeter, etc.) involve perceptual judgments that are hard to teach with a simulator. This is probably the reason why OJT supervisors favor hands-on aircraft training. We feel that IMIS would be less effective at training perceptual-based procedures, at least when it is used in a *stand-alone mode. Some of the problems of* teaching the perceptual aspects of maintenance can be solved by using an IMIS simulator with the aircraft or other, more realistic simulators. *Therefore, we hypothesize that an IMIS simulator* can help teach maintenance skills in three different configurations: with the aircraft, with the existing Air Force maintenance simulators *("flatboard" simulators), and in a stand-alone* configuration.

We envision two levels of detail in an IMIS *simulation. The first, which we call a detailed* simulation, involves augmenting the CDM with instructional information for each aircraft sub-system. This would use the full capabilities of IMIS to present maintenance training. However, authoring and updating the instructional information needed for a detailed simulation could prove expensive, especially if IMIS is used, as planned, for multiple aircraft. This led us to consider a second level of detail in simulation, what we call generic simulation. This would use minimal authoring of instructional materials, instead relying on knowledge and data already in the Diagnostic Module and the CDM. As we mentioned previously (in discussing Step 2), in its job-aid capacity, IMIS contains considerable knowledge about aircraft systems and maintenance processes. This information overlaps considerably with the knowledge used by expert human troubleshooters. As will be described below, we feel that the information currently in the CDM is enough to create a powerful simulation environment, if it is presented to students using appropriate instructional strategies. The generic simulation would require minimal authoring and updating beyond that needed to create the CDM. Once, initially developed, the generic simulation capability would be available at little extra cost for any aircraft with a CDM that can support IMIS job aiding.

In the following, we will outline the features that could be included in a generic IMIS simulation. As mentioned above, the simulator will follow the principles of cognitive apprenticeship training.

Realistic Practice - The first feature of apprenticeship training, already discussed here, involves allowing students extensive problem-solving practice. However, if this practice is to be *beneficial, the kind of problems students practice* on is important. Initially, students need to practice problems that involve routine use of the TOs, as is done with the flatboard simulators. *This will teach students procedures knowledge.* Later, students need to practice difficult problems that cannot be solved solely by the TOs. This will require them to learn and use the other kinds of *knowledge needed for expert troubleshooting.* The capabilities of the IMIS Diagnostic Module potentially can allow it to solve some problems that the TOs alone cannot solve. However, *IMIS's ability to provide more accurate* troubleshooting advice than the TOs has not yet been convincingly demonstrated. If this ability is demonstrated, it would be possible for an IMIS simulator to generate difficult ("beyond the TOs") problems and use the intelligence in the Diagnostic Module to coach students on these problems.

Coaching - A second principle of cognitive apprenticeship involves coaching students as they solve problems. Coaching includes modeling expert problem-solving behavior and thinking, as well as giving feedback in the form of questions, hints, and reminders. We think that IMIS can provide this kind of coaching, using the knowledge in the Diagnostic Module and the CDM. Furthermore, this coaching can help students learn most of the knowledge needed for expert troubleshooting. For example, when the Diagnostic Module uses the half-split strategy to choose a test, the coach could describe this strategy to students. This is an example of modeling. Later, the simulation could give students the chance to choose their own tests and replacements, before seeing the Diagnostic Module's recommendations. At this point, the coach could determine whether the tests a student chose reflect use of half split. If they do not, the coach could remind the students of the strategy.

This example reflects a general instructional strategy of first having the Diagnostic Module model appropriate troubleshooting knowledge as the student is solving a problem. Later, the student is given more responsibility for decisions during problem solving (e.g., choosing their own tests). At this point, through questions and feedback, the coach focuses the students on the appropriate troubleshooting knowledge for the current decision. This instructional strategy could be used to instruct most of the knowledge in Table 1, in particular, symptom-fault associations, procedures, strategies, and some coordination processes. As mentioned earlier, instructing students in mental-model knowledge in a generic simulation (i.e., without adding information to the CDM) would be difficult, since the CDM contains little mental-model knowledge.

Fading - A third principle of cognitive apprenticeship is fading, whereby the coach withdraws support as the student becomes more proficient. A simple way to implement fading would be to have different levels of coaching in the generic simulation. The novice level would focus on the coach modeling and explaining the troubleshooting process, with the students having little input into the decision making. An intermediate level would allow students to have more input into decisions during problem solving, but the coach would ask questions and give feedback to ensure they were using the correct knowledge in making those decisions. The expert level would provide no coaching, allowing the students to make troubleshooting decisions as if they were using IMIS on the flightline. The instructor or the students could choose which level of coaching to use for a particular problem.

An even more effective way to implement fading would involve some student modeling. As will be described in the assessment section, a diagnostic capability could be added to the generic simulation, giving it the ability, for example, to evaluate and remember how well a student knows the half-split strategy. Given this information in a student model, the coach could determine what kind of coaching to give concerning this strategy. A student modeling capability would allow more tailoring of instruction to individual needs than simply having novice, intermediate, and expert simulations, but would be more costly to develop.

Collaborative Learning - A fourth principle of cognitive apprenticeship is to encourage collaborative problem-solving among students. This principle is already being followed in the use of the flatboard simulators in Technical School and the Field Training Detachment. Students solve problems in pairs with the instructor occasionally offering assistance or coaching. We recommend that this practice continue with IMIS simulators. In addition, other forms of collaboration are possible (Katz & Lesgold, in press). For example, students could pose problems for each other. Or, a student's performance on a troubleshooting problem could be recorded using IMIS's recording capability and later replayed for discussion by other students or the instructor. With appropriate guidance by an instructor, a classroom or learning laboratory with a number of IMIS simulators could become a rich environment for student interaction and learning.

All of the instructional features described above could be implemented in a generic IMIS simulator that uses just the CDM knowledge needed for job aiding. The detailed simulator could build on these features in a number of ways. For example, the IMIS authoring system could be used to add mental-model information to the CDM so that students could be coached in this kind of knowledge. Also, videodisk or virtual-reality capabilities could be added to the simulator. This would be of particular help in teaching students some of the perceptual aspects of maintenance activities. For example, when removing and replacing a component as part of a troubleshooting problem, students could use the videodisk screen to see what the component looks like and where it is located on the aircraft. A videodisk capability like this is already implemented for the flatboard simulators used in Technical School and the Field Training Detachment.

Assessment Uses

An IMIS simulator could perform two types of student assessment: 1) detailed diagnosis of students' strengths and weaknesses for use by an instructor, and 2) more general evaluation of student readiness for course advancement or particular work tasks. We will describe the diagnostic assessment first.

As we mentioned earlier, a generic IMIS simulator could do some simple student modeling. For example, the simulator could obtain information about a student's use of the half-split strategy by having the student choose troubleshooting tests and replacements before seeing the Diagnostic Module's recommendations (e.g., as in the intermediate level simulator described above). Using information available in the CDM, the simulator could immediately evaluate each proposed test and replacement in terms of how well it conformed to the half-split strategy. This information could be used to update a variable in a student model representing knowledge of this strategy. A similar approach could be used to model student knowledge of other strategies (e.g., elimination), symptom-fault associations, and some coordination processes. This modeling could be done as part of the generic IMIS simulator, since it relies on knowledge currently in the CDM. Only limited mental-model knowledge could be modeled using information currently in the CDM.

The information in a student model could be used in two ways. First, the simulator could use this information to tailor its coaching to individual student needs, as students work on problems. This would involve implementing the capabilities of a full-fledged intelligent tutoring system (ITS). We think this is possible, given the current configuration of the Diagnostic Module and the CDM, although the student model would be limited, in that it would not represent all the knowledge required for expert performance. A second, and less costly, way to use the detailed diagnostic information in a student model would be to print out a report describing a student's knowledge. The instructor could use this report to plan instruction, and/or students could use it to plan their studying.

A second kind of assessment that could be provided by an IMIS simulator is a general evaluation of student readiness for course advancement or job performance. For example, a supervisor could assign a student to practice a certain troubleshooting task on the simulator. When the student is ready, he or she could take a test run through the simulator on that task. The simulator could then print out a report comparing the student and the simulated expert (i.e., the Diagnostic Module) on information such as the number of tests and component replacements performed and simulated maintenance time. This information could help the supervisor decide whether the student was ready to perform this task on the flightline.

The above assessment functions could be performed by a generic IMIS simulator, with minimal changes to the CDM. A more detailed simulation could focus on functions such as assessing students' mental-model knowledge.

To summarize our ideas concerning an IMIS simulator, a generic IMIS simulator could be developed with the instructional and assessment capabilities described above (i.e., extended problem-solving practice, coaching, fading, collaboration, assessment reports, and limited student modeling). This simulator could use the intelligence and information currently available in the Diagnostic Module and CDM, and thus would not require extensive and costly authoring of instructional materials. The simulator would follow effective principles of instruction (cognitive apprenticeship) and implement some features of an ITS. We hypothesize that such a simulator would have a number of beneficial effects, including:

- increasing student practice of maintenance tasks;
- increasing student knowledge of the problem-solving skills necessary for expert troubleshooting (cf., Table 1);
- reducing training time without requiring additional instructors; and/or increasing students' proficiency levels;
- increased acceptance of computer-based training in on-the-job training on the flightline.

However, some of the troubleshooting processes used by the current version of IMIS, particularly those involving mental-model knowledge and coordination processes, are significantly different from those used by humans. Therefore, in its current state, IMIS probably could not be used to train advanced troubleshooting skills (e.g., for skill-level 7 technicians). IMIS currently offers more potential for training novice technicians, although even for training novices, the addition of some mental-model knowledge to IMIS is recommended.

Using the generic IMIS simulator as a base, a more detailed simulator could be developed with increased use of mental-model knowledge and video-based output (video or virtual reality).

CONCLUSION

In this paper, we have described our procedures for adding training capabilities to the IMIS system. After performing a baseline analysis of current Air Force maintenance training practices, we followed a three-step process of *conducting a cognitive task analysis* of maintenance tasks (especially troubleshooting), comparing IMIS's knowledge and algorithms to those of human experts, and developing a plan for the IMIS training system. Information from the early steps in this process was quite useful in developing the training system plan. In particular, the concept of a generic IMIS simulation followed quite closely from the cognitive task analysis and the comparison of IMIS's capability to the task analysis. The generic simulation has the potential for providing effective but low cost training by using the knowledge already available in the IMIS job aid.

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