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Traditional maintenance training curricula use paper technical manuals to teach "tricks of the trade" in corrective and preventive maintenance which require multiple adjustments, lengthy calibrations and labor intensive test/checkout procedures. Rotation often delays personnel assignment to a platform which requires these maintenance skills. The non-availability of skilled maintenance personnel poses a tremendous threat to readiness conditions for mission critical equipment. In order to best support the Navy's maintenance requirements and improve maintenance efficiency, the Naval Research Laboratory at Stennis Space Center, Mississippi developed an Expert Maintenance Advisor (EMA).

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AN EXPERT SYSTEMS TECHNOLOGY APPROACH TO MAINTENANCE PROFICIENCY

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ABSTRACT

Traditional maintenance training curricula use paper technical manuals to teach "tricks of the trade" in corrective and preventive maintenance which require multiple adjustments, lengthy calibrations and labor intensive test/checkout procedures. Rotation often delays personnel assignment to a platform which requires these maintenance skills. The non-availability of skilled maintenance personnel poses a tremendous threat to readiness conditions for mission critical equipment. In order to best support the Navy's maintenance requirements and improve maintenance efficiency, ·e Naval Research Laboratory at Stennis Space Center, Mississippi developed an Expert Maintenance Advisor (EMA).

This paper discusses an approach which implements Expert Systems technology methods to develop an expert maintenance reference. It also addresses the impact of performance support systems and interactive electronic technical manuals in maintenance training.

INTRODUCTION

The Expert Maintenance Advisor (EMA) is an expert maintenance training reference tool and performance support system for system level components. It was developed to augment rather than remove or replace the need for maintenance personnel. The heart of the system is an intelligent interactive electronic technical manual which is not just an automated technical manual or page turner but an expert reference tool. Its current configuration uses commercial-off-the-shelf hardware/software to achieve faster access/data retrieval time and embedded subject matter expertise to provide increased user proficiency. Its integration into maintenance training curricula will influence maintenance training objectives through rapid diagnostics, troubleshooting, fault localization and increased maintenance proficiency. An EMA reinforces maintenance training objectives because on-line expert advice is a part of the system from cradle-to-grave and most importantly available during training at the schoolhouse, ashore and afloat. Figure 1 shows a description (Kearsley, 1982), of learning efficiency as a curvilinear relationship between time and proficiency. The novice quickly masters basic material because there is a rapid acquisition of new knowledge and skills at the beginning of instruction. As the complexity and sophistication of the task increase, the time required for incremental improvements in proficiency lengthen, thus skill degradation is rapid without application reinforcement.

Two major EMA benefits are paper cost and weight reductions. Presently, within the Navy/Marine Corps, 237 million drawings and 15 million technical manuals costs $4,000,000,000. The USS Vincennes stores 23.5 tons of paper above the main deck. This is more tonnage of paper than weapons, therefore paper weight is a BIG deal. Paper cost/ weight reductions, subject matter expertise availability, and portability benefits alone are value-added to learning efficiency, performance efficiency, and

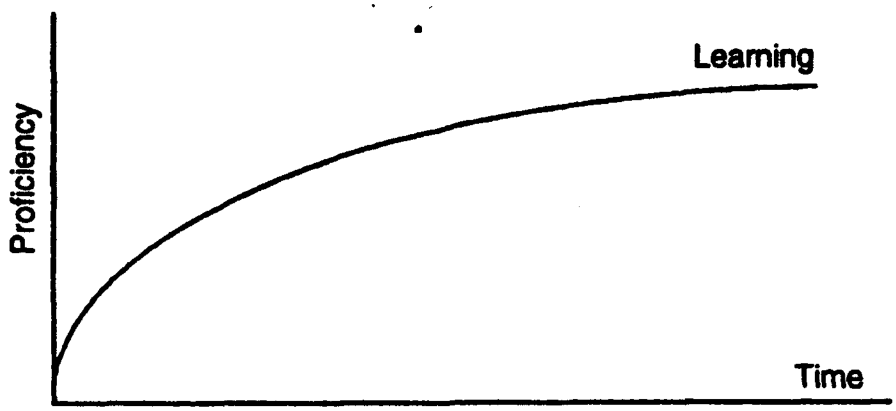

Figure 1. Learning Efficiency

maintenance effectiveness; and cost savings for technical information reproduction and storage requirements. Army and Air Force statistics are of similar magnitude.

Expertise can be defined as the specialized knowledge that permits an individual to excel at a given task. This specialized knowledge is typically obtained through extensive experience, after training in the basics has been assimilated. It is not a commodity that can be easily or quickly transferred from one individual to another. It can, however, be readily available by one individual to another through expert consultation. The primary purpose for embedding such expertise provides expert guidance to an intelligent user with less experience, without requiring a human expert to be present. The techniques for capturing expert knowledge and structuring it into a workable computer program are collectively categorized as Expert Systems development (Holland, 1986).

The misdiagnosis of a problem can put a combat system out of action and uselessly deplete the supply of the component which is removed and replaced. Traditionally, skill in troubleshooting came about as a by-product of years of experience with a system, and an apprenticeship served under a master troubleshooter. This critical skill became even more valuable because of the costly manner in which it was acquired. These costs include apprenticeship, journeyman, and master troubleshooting skills development which extend over the military and post-military careers of the trainer and trainees. Conventional classroom training requires logistics, travel, courseware, and firmware costs. The payoff for training dollars invested comes from improved job performance. The best evidence of this was demonstrated during the Persian Gulf War. The cost of maintenance, measured as the expense of restoring operational readiness, is probably determined by the accuracy of fault identification more than any other factor. Determining a system problem doesn't seem costly, after all nothing is being consumed except time. But the fact is that time is often the most costly resource. Therefore the true measure of valuable training is operational readiness.

The challenge we must meet is reduction of the time required to gain this experience. In this sense, training is synthetic experience, and as with most synthetics, there are aspects which are effective in substitute form. Even more desirable is an increase in efficiency, where a higher level of skilled performance is reached, even though costs are reduced. Cost effectiveness is a baseline requirement, but in the foreseeable future, those who can bring about cost efficiency will be meeting the true need (Bresee & Greenlaw, 1992). Certainly, money spent for training using an EMA is a wise investment which yields a solid investment return, viz., increased maintenance proficiency.

SYSTEM FEATURES

Expert Systems development techniques capture expert knowledge and structure it into a workable computer program (Holland, 1986). An Interactive Electronic Technical Manual (IETM) combines artificial intelligence with electronic information delivery techniques in order to create a paperless troubleshooting and repair environment, (Long & Lontos, 1992). The Expert Maintenance Advisor couples Expert

Systems technology and IETM techniques to develop a reference tool that provides assistance during troubleshooting, system diagnostics and maintenance turn-on procedures. It uses embedded subject matter expertise to guide maintenance personnel through a logical event sequence. A reference section of helpful hints provides "rules of thumb" to reinforce learned maintenance skills. The menu-driven system resides on a laptop computer in a DOS 4.01/C Programming Language environment. It requires a 120MB hard drive and 4MB of RAM which includes 3MB of extended RAM for storage and quick retrieval of textual data and graphics. Hypertext and highlighting features are included for all technical manual ref-

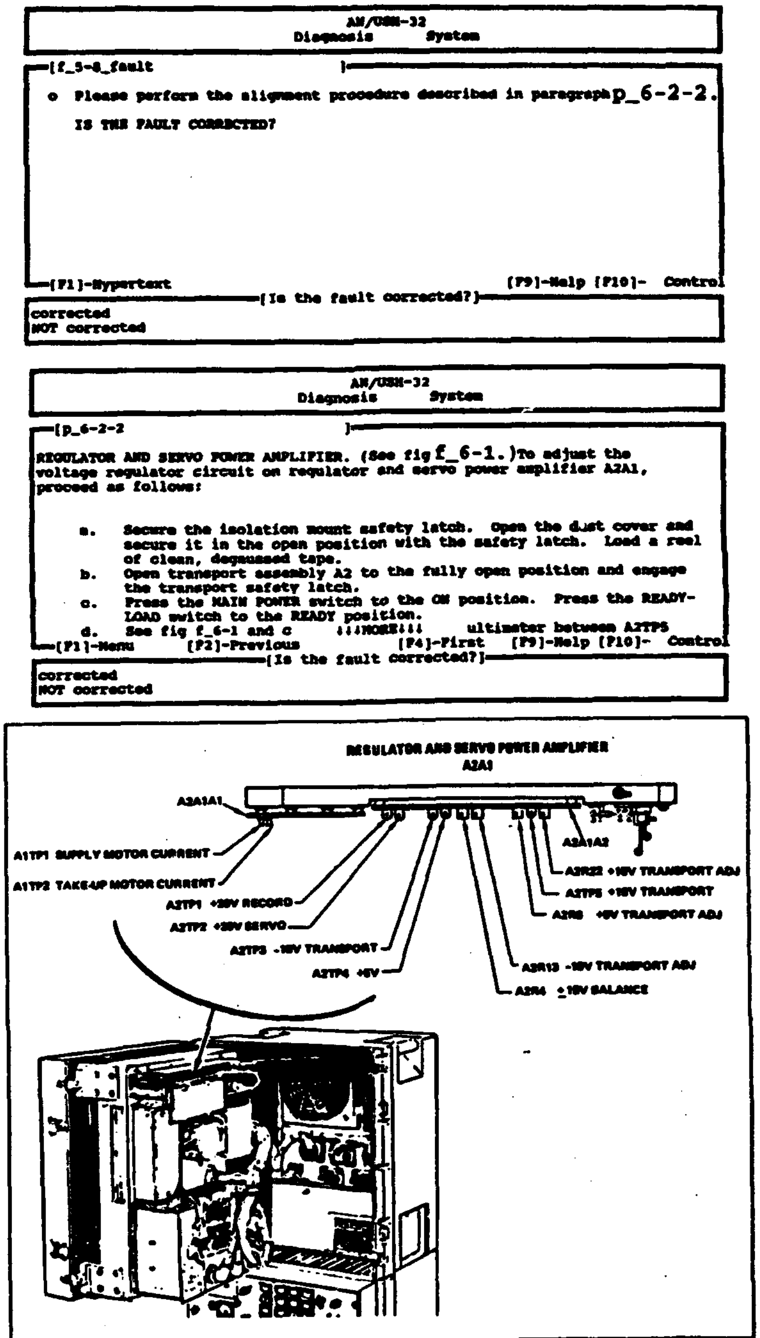

Figure 6-1. Regulator and Servo Power Amplifier A2A1, Location of Test Points and Adjustments

Figure 2. Hypertext Screen Reference and Figure.

erences. Figure 2 shows these references in bold on the screen and allows the user to go directly to them using the F1 and TAB function keys.

Knowledgebase updates can be done without source code recompilation and independent library routines generation for the source code and rule language make the system adaptable to multiple corrective/preventive maintenance system application developments. Its portability makes it easy to use in limited work spaces and its availability on electronic media enables maintenance personnel to perform tasks rapidly. Figure 3 shows the AN/USH-32 Signal Data Recorder-Reproducer Set, its Expert Mainte-

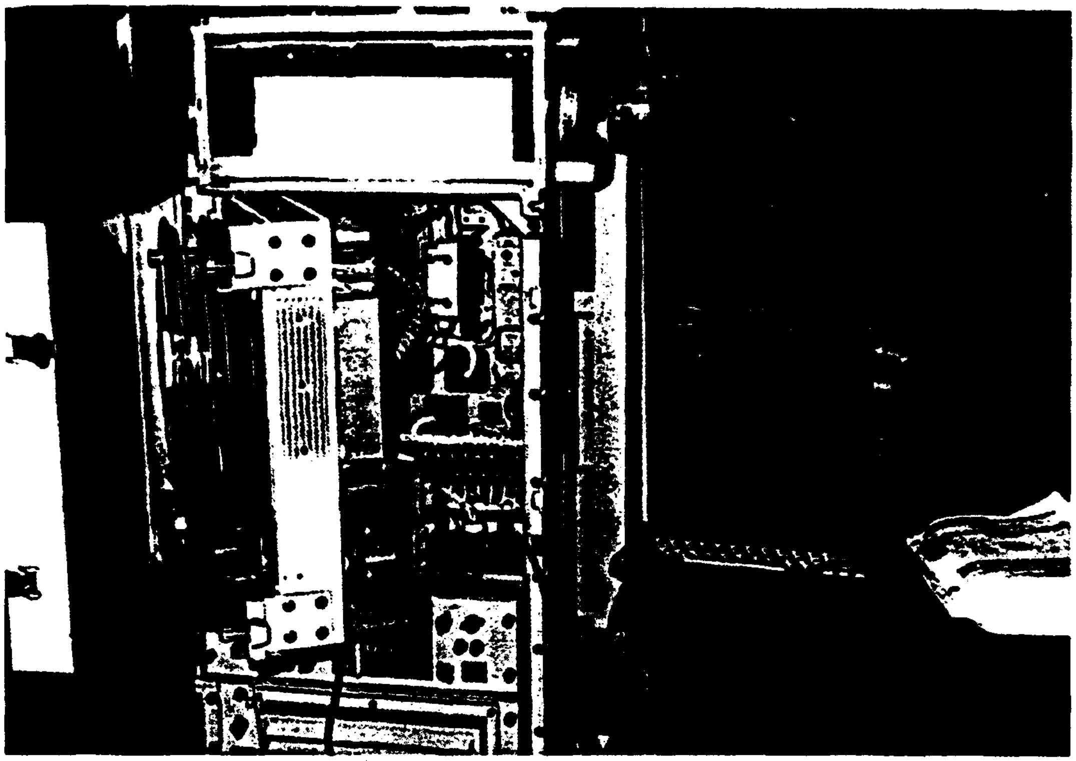

Figure 3. AN/USH-32, Expert Maintenance Advisor

nance Advisor, and one of its conventional maintenance manuals (Harris & Romalewski, 1994).

When a complex system fails, the maintenance goal is to efficiently get it fixed and back on line. The application of expert systems techniques to the development of maintenance advisors offers the greatest potential for significant increases in maintenance performance. These performance measurements can not be documented until system deployment, utilization, and evaluation statistics are available. Maintenance advisors make maximum use of basic maintenance training and existing built-in test capability while providing near instantaneous access to pertinent maintenance information.

EMAs provide an on-board training opportunity for the novice who has not performed maintenance actions or trained maintenance personnel in need of an equipment maintenance refresher. EMA system developers and subject matter experts link equipment maintenance learning objectives and other maintenance requirements in the EMA development phase using input from shipboard, shore-based, and training community users. Pop-up windows, helpful hints, textual/graphical references enhancements are used to capture the user's interactive response during EMA sessions. Another useful feature is the session save which allows the user to leave the session and return to the session at the last process step. In the session replay mode troubleshooting problem-solving routines which are performed by the user can be stored and recalled later. This allows users to receive continuous training no matter where they are

(Buehler, 1992)! Specific maintenance actions, troubleshooting skills and performance are effective when the cause of the fault and its relationship to system components are visible to the user.

Expert Systems are adaptable in shore-based environments, where a significant portion of the training pipeline is dedicated to student familiarization of the organization and use of the technical manual contents. While these requirements are pertinent to effective training, the greatest impact is seen in the length of training courses and their associated costs. Expert Systems provide a reduction in training cost and training time without degradation of training effectiveness in a shore-based environment as well as a shipboard environment.

PERFORMANCE SUPPORT SYSTEMS IN MAINTENANCE

Performance Support Systems (PSS) are computer-based systems that use knowledge-based systems, hypertext, on-line reference, extensive data bases, and allied technologies to provide support to performers on the job, where they need it, when they need it, in the form most useful to them. The four basic PSS functions are librarian, advisor, instructor, or dofer that does work with or without assistance from the human performer (Carr, 1992). They are an asset to maintenance technicians because they provide a specific solution to an identified maintenance problem. Portability and ease of use take the strangeness out of the Expert Systems and make them more accessible and exciting for users. They enhance prior training knowledge and increase skill level in a shore-based as well as in a shipboard environment. It has been proven many times that "if you don't use it, you'll lose it". However, with the onset of Expert System technology, a counter theory may support the idea that "if you don't use it, Expert Systems can revive it". When a complex system fails, the maintenance goal is to efficiently get it fixed and back on line. Expert Systems technology developments offer the greatest potential for significant increases in maintenance proficiency. EMAs make maximum use of basic maintenance training skills and existing built-in test capabilities while providing near instantaneous access to pertinent maintenance information.

An EMA is a portable computer, programmed using Expert Systems techniques to give a maintenance technician expert knowledge on a specific item of equipment. The technician must be trained only in the basics of troubleshooting and repair. S/He does not need specialized training on the unit requiring repair. The EMA itself contains the expert information acquired from system developers, maintenance manuals, and subject matter experts. This broad spectrum of information resides within the maintenance advisor and is readily available to maintenance personnel. It does not require a paper technical manual search to retrieve the necessary information to continue with maintenance procedures. As shown in Figure 2, the screen highlights reference links (text and graphics) to pertinent information for all maintenance procedures. The availability of the complete text/graphics information from the technical manual and embedded expert knowledge in the form of helpful hints are key features of the EMA. Access to this information allows less experienced maintenance technicians to perform with on-line expertise. The EMA functions as a support system to keep systems operational, i.e., reduce meantime between failure and improve maintenance efficiency.

PSS offer a fertile field for knowledge-based technology. They represent a solution looking for a problem by identifying how performance can be improved and using the technology that best accomplishes this goal effectively and efficiently. Support to performers on the job where they need it, when they need it, and in form most useful to them is critical in system maintenance. The EMA functions as an advisor which embodies and shares some specialized expertise necessary to carry out the maintenance task. An added feature of a properly designed performance support system not only supports performance but develops the performers skills (Carr, 1992).

The integration of interactive electronic technical manuals and Expert Systems technology advances state-of-the-art equipment maintenance techniques. Conventional training coupled with these techniques increases trainee and training objective effectiveness. The advent of a paperless Navy and Computer-Aided Acquisition Logistics Support (CALS) initiatives make this Expert Systems technology approach a bellwether in maintenance proficiency.

Expert Systems technology integrates IETM into training requirements and upgrades training capabilities. It also supports CALS initiatives to improve systems quality, reduce development time, and avoid cost through use of computer technology. This approach puts the user in the driver's seat by placing the primary focus on satisfying end user requirements. It supports the "create once use many" philosophy and benefits both technical information and end-user computer systems applications.

EMA DEVELOPMENT AND USER EVALUATION

The EMA was developed using C Programming Language and a backward chaining inference engine to manipulate facts, rules, and goals. Technical manual logic diagrams, preliminary procedures/general notes, and the maintenance turn-on procedure are the rule-base foundation. Knowledge acquisition sessions were conducted with subject matter experts to embed Maintenance Hints for the system.

The EMA was evaluated by trainees and a private contractor during its operational suitability testing. The evaluation summary is listed below.

1) Easy to use

2) Accurate

3) An Asset To On-Going Automated Efforts

4) Provides reliability/supportability

5) Increases corrective/preventive troubleshooting efficiency

These are preliminary evaluation results. A comprehensive EMA evaluation can best be determined after it has been used extensively in the problem domain. The final evaluation will answer questions which address decision making, control strategy, inference rule correctness/consistence/completeness, conclusion organization/order, and level of detail capabilities. Users in the field demand more that just high- quality performance; they want a system to be fast, reliable, easy to use, easy to understand, and very forgiving when they make mistakes. Thus the EMA needs extensive field testing before it will be ready for Fleet use (Waterman, 1986).

EMA CURRENT USE

The EMA is not currently being used in fleet maintenance. Its next testing phase is validation and verification. The nature of Integrated Logistics Support for system deployment to training facilities, organizational/ intermediate/depot level maintenance facilities, or shipboard requires comprehensive planning and scheduling. Training and shore-based maintenance facilities will probably be the first extensive system users.

EMA LIMITATIONS AND FUTURE ENHANCEMENTS

Limitations cited in the evaluations were graphics viewing resolution, graphics speed, and visual voltage level readout observations. Graphics viewing resolution and speed can be increased using newly developed graphics packages. System acquisition and display of digital readout voltage levels using analog-to-digital electronic interface between the EMA and AN/USH-32 are feasible. Computer and electronic firmware, hardware, and software are available to resolve these limitations and they will be incorporated as system modifications. Rapid advancements in these product areas will keep Expert Systems technology developments for equipment maintenance on the leading edge.

CONCLUSION

Expert Maintenance Advisors, Performance Support Systems and Interactive Electronic Technical Manuals impact equipment maintenance requirements significantly in the wake of cutbacks and rightsizing. They are the answer to cost effectiveness without lost in performance efficiency. Expert Systems technology lends itself to cost effective implementation using commercial-off-the-shelf, government-off-the-shelf and non-developmental items. Performance is the measure of success in any operational system, therefore readiness is the key to performance efficiency in maintenance. System level component maintenance relies heavily on the training community's capability to provide personnel with the necessary skills to keep systems in a fully operational condition. Expert Systems technology offers the best approach to achieving maintenance proficiency by initiating new maintenance curricula and reinforcing learned maintenance training skills.

REFERENCES

Bresee J. & Greenlaw, D. (1992). Cost Efficient Maintenance Training Through Cognitive Fidelity. Proceedings of the 14th Interservice/Industry Training Systems and Education Conference (pp. 685-691).

Buehler, S. (1992). A Systems Approach to Automated Technical Manual Development. Proceedings of the NAVAIR Third Annual Airborne Weapons Training Exposition and Technology Review (pp. 126-131).

Carr, C. (1992). Performance Support Systems: A New Horizon for Expert Systems. AI Expert Magazine, 44-49.

Harris, P. & Romalewski, R. (1994). Expert Maintenance Advisor Development for Navy Shipboard Systems. Proceedings of Second World Congress On Expert Systems. Lisbon/Estoril, Portugal, Cognizant Communications Corp.

Holland, C. R. (1986). Expert Systems for the Naval Oceanography Project. Technical Report 166, Naval Ocean Research and Development Activity, National Space Technology Laboratories, Mississippi.

Kearsley, G. (1982). Costs, Benefits, & Productivity in Training Systems. Reading, MA: Addison-Wesley.

Long, J. & Lontos, J. (1992). Interactive Electronic Technical Manuals Increase Weapon System Readiness. Defense Electronics Magazine, 54-57.

Waterman, D. A. (1986). A Guide To Expert Systems. Reading, MA: Addison-Wesley.