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Personal Electronic Aid for Maintenance: Final Summary Report

Robert A. Wisher and J. Peter Kincaid

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This report summarizes the findings from both Army and Navy evaluations of the Personal Electronics Aid for Maintenance (PEAM), which is a prototype electronic technical information delivery system capable of displaying step-by-step procedural information to technicians during their performance of maintenance tasks. The results demonstrate a nearly 6:1 advantage of PEAM (and its emulation on other microcomputers) over traditional, paper-based approaches to troubleshooting tasks, as well as a nearly 2:1 advantage in other tasks. The advantage was measured in terms of average errors per task. The report offers a set of enhanced functional characteristics based on lessons learned and supports electronic technical information delivery as a system for potentially reducing maintenance errors.

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Research Report 1516

Personal Electronic Aid for Maintenance: Final Summary Report

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Education and Training Systems

FOREWORD

To ensure that soldiers can maintain the Army's future weapon systems, the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) performs behavioral research to develop job aids that can assist the soldier in maintaining a complex system. Within the ARI Training Research Laboratory, the Development Engineering Office (DEO) provides management oversight for applied research on prototype development and evaluation of a product by two or more services as part of the Joint Services Manpower and Training Technology Development Program.

This summary report of the Personal Electronic Aid for Maintenance (PEAM) was prepared by the DEO in cooperation with the Technology for Skills Acquisition and Retention Technical Area and the Orlando Field Unit. The Naval Training Systems Center was the principal developer, and the Navy Personnel Research and Development Center performed the Navy test. The results of this work will serve as input to the Department of Defense Computer-Aided Acquisition and Logistics Support program and to the development of the Militarized Electronic Information Delivery System by the Army Materiel Command.

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EXECUTIVE SUMMARY

Requirement:

Printed texts provide the information necessary to support the operation and maintenance of virtually all systems and equipment in the Armed Forces. A steady growth in the size of technical documentation has created problems in accessing technical information, where technicians must repeatedly cross-reference through single volumes or search through multiple volumes of manuals to obtain needed information. Consequently, critical troubleshooting procedures are bypassed, and the likelihood for removal of nonfaulty components increases. This problem has been recognized within the Department of Defense by the Computer-Aided Acquisition and Logistics Support (CALS) initiative, and within the Army by a draft Required Operational Capability for the Militarized Electronic Information Delivery System (MEIDS).

Procedure:

A prototype electronic information delivery system called the Personal Electronic Aid for Maintenance (PEAM) was developed by the Joint Services Manpower and Training Technology Development program for evaluation by the Army and Navy. The Army evaluated PEAM on maintenance tasks for the M1 Tank Turret; the Navy evaluated it on maintenance tasks for the NATO SEASPARROW Missile System. Because of technical problems with the four prototypes, simulations of PEAM on commercially available equipment were also used in the evaluation. Comparisons were made of the effectiveness of PEAM and its simulations, relative to the effectiveness of paper-based technical documentation, in terms of average errors per task and time to task completion.

Findings:

The results showed that the PEAM approach reduced troubleshooting errors by about a 6:1 ratio in the Army test, and about a 5:1 ratio in the Navy test. In the nontroubleshooting tasks (Army only), there was about a 2:1 advantage for PEAM. Time to task completion was reduced by 25% in the Navy test; in the Army test, the time to task completion increased slightly because of the slow display rate for graphics. Although these differences are sizable, they should be interpreted with caution, since there were comparability problems between experimental conditions. These results demonstrate the potential of electronic delivery for reducing maintenance errors.

Utilization of Findings:

These findings contribute to the formulation of future electronic technical information delivery systems under consideration by the CALS, MEIDS, and

other programs. Important lessons ere learned on the advantage of a standardized authoring and operating system before database development and the advisability of pursuing nondevelopmental items where practicable.

PERSONAL ELECTRONIC AID FOR MAINTENANCE: FINAL SUMMARY REPORT

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Final Summary Report

INTRODUCTION

General

The purpose of this report is to summarize the findings of the Personal Electronic Aid for Maintenance (PEAM) project, which was completed in December 1987. The findings take several forms: first, there are the empirical results from user tests in the Army and Navy; second, there are the results of a user survey regarding the use of electronic delivery devices instead of printed technical information; and third, there are the lessons learned on the design of the hardware and the development of the databases. Taken together, these findings form the basis for proposed enhancements of future electronic technical information delivery systems.

The report is summary in nature. More detailed information on user tests by the Army and Navy are available in Schurman and Kincaid (1988) and Smillie, Nugent, and Sander (1988) respectively.

Background

Printed texts—particularly technical manuals (TMs)—provide the information necessary to support the operation and maintenance of virtually all systems and equipment in the Armed Forces. Nevertheless, there are at least five major limitations inherent in paper-based TMs that have become increasingly evident over time:

(1) The sheer volume and weight of paper required to document the necessary technical information;

(2) Problems of organizing and indexing the material so that needed information can be accessed readily by users;

(3) The relative inflexibility of conventional TMs for accommodating the information needs of users with varying skill levels;

(4) The lack of a dynamic interactive capability between the TM and user;

(5) The time and dollar costs associated with the production, distribution, updating, and correction of TMs.

One consequence of the steady proliferation of military technical documentation involves access problems: technicians often must search through multiple volumes of TMs to obtain needed information. A dramatic example of this access problem is described in a report issued by the General Accounting Office (1979). The report notes that, to isolate and repair one particular radar malfunction on a C-141 aircraft, technicians had to refer to and cross-reference 165 pages in 8 separate documents.

Another example of the cross-referencing demands of a TM appears in a three-page troubleshooting procedure examined during the evaluation of PEAM. The three-page procedure of eleven steps makes references to eight other procedures. These references, in turn, call for the use of other references. A total of 38 references are used in performing the basic eleven-step procedure. This total represents some duplication, as some general information and common procedures are referenced from several procedures. Including these procedures, the actual number of referrals is 59.

An unfortunate by-product of difficulties in accessing required technical information is that it tends to discourage users from following maintenance procedures specified in the TM. Thus, whenever critical troubleshooting procedures are bypassed or trial-and error practices are used in lieu of "doing it by the book," the probability increases for higher removal rates of non-faulty components. Confirmatory evidence of this assertion is provided in a study that examined the causes of unnecessary removals of line replaceable units on Air Force avionic equipment (Rue & Lorenz, 1983). Results of this study showed that 13 percent of 1,008 unnecessary replacements were attributed to ineffective technical orders (e.g., troubleshooting procedures were difficult to follow, or took too long to perform, or were inaccurate). Deficiencies in TMs were also reported as a contributing factor to unnecessary replacements of non-faulty components in a tri-service field study by Orlansky and String (1981). Access difficulties can lead to an increase in maintenance errors.

Another major shortcoming of paper-based TMs is that the information they contain is static; hence they cannot readily be adapted to the needs of the user. For example, an inexperienced technician, or one who has not worked on a particular equipment for some time, may require more detailed information than is provided in the TM to perform such functions as locating test points, removing, replacing, or adjusting components. Conversely, highly experienced technicians may have performed a particular maintenance task so often that they need little more than a checklist to ensure that no maintenance step is overlooked.

One attempt to solve this problem—particularly for entry-level military maintenance technicians—is the development of highly proceduralized and illustrated manuals, known as job performance aids (JPAs). Numerous studies have shown JPAs to be effective both in terms of their method of reorganizing and reformatting technical information and in improving job task performance. (See Foley & Camm, 1972; Johnson, Tnomas & Martin, 1977; and Smillie, 1985 for reviews of the JPA literature.) These advantages notwithstanding, several problems have inhibited the use of JPAs in military settings. For example, because JPAs are intended primarily as supplements to, rather than as replacements for conventional TMs, they add to the proliferation of technical information. Another problem is the time factor since the development of JPAs frequently requires substantial investment both in terms of front-end analyses and subsequent verification of the information. These factors result in

JPAs that are equally as, and in some cases, more costly to design, produce, and update than conventional TMs.

Paper-based approaches to technical information do not offer a dynamic, interactive capability between the information source and user. This is true, of course, for both TMs and JPAs. They cannot, for example, provide hands-free access to, or alternative methods for, delivery of needed technical information, such as through text-to-speech output devices. Neither can they highlight or animate selected portions of the technical information "on demand," such as emphasizing the physical location of components, or highlighting the path of a signal. The application of new technologies to promote the advantages of JPAs to the users and to address the inherent problems of paper-based approaches were motivating factors for the development of PEAM.

Although electronic technical information delivery systems offer advantages over TMs and JPAs, they do not necessarily avoid the time and dollar costs associated with the production, distribution, and corrections of technical information. These problem areas might be mitigated through the development of authoring systems and electronic distribution networks.

During the development and evaluation of PEAM, other applications of electronically delivered technical information were under investigation. These include:

- CMAS - Computer-based Maintenance Aid System. See Clay (1986) and Nugent, Sander, Johnson, and Smillie (1987).
- NTIPS - Navy Technical Information Presentation System. See Fuller, Post and Mavor (1987).
- EMPS - Electronic Maintenance Publication System. See MRSA (1987).

The breadth of these projects underscores the Department of Defense (DoD) interest in the topic of electronic delivery of digital logistic technical information. Indeed, DoD has established a Computer-aided Acquisition and Logistic Support (CALS) program to increase capabilities to receive, distribute, and use logistic technical information in digital form. CALS is also oriented toward accelerating the automation of contractor processes for generating logistic technical information products. A near-term goal of CALS is to develop recommendations for functional specifications relating to delivery of TM information to users in electronic form for interactive access. The results of the PEAM project will hopefully contribute to this goal.

PEAM Development

The PEAM project began with a concept definition effort jointly sponsored by the Naval Training Systems Center (NTSC), at that time the Naval Training Equipment Center, and the Army Project Manager for Training Devices (PM-TRADE). The initial effort, which was completed during the third quarter of FY82, resulted in an overall concept formulation and design analysis. Next, detailed sp[illegible]fications were developed for designing a portable maintenance informatic[illegible] delivery system and supporting software. During the same year, a memorandum of understanding was issued between the Army Research Institute and the Naval Training Systems Center. The memorandum established agreements, support, and resource responsibilities for the prototype development phase of PEAM. The Joint Services Manpower and Training Technology Development Program sponsored the development and evaluation of the PEAM prototype. Major milestones of the project were:

- FY80 — Formulated the conceptual definition for PEAM.
- FY82 — Completed the hardware and software development specifications.
- FY82 — Contracted for the development of PEAM.
- FY86 — Contractor delivered four PEAM prototypes.
- FY87 — Completed test and evaluation.

Description of PEAM

The PEAM software includes a front-end system for converting, compiling, and storing maintenance databases onto computer-readable media, termed memory modules. The modules, in turn, are plugged into the computer-based delivery system for subsequent use by the field technician. Collectively, these subsystems are expected to have advantages over existing paper-based maintenance documentation in that they: (1) offer greater versatility in the way information can be organized and accessed; (2) reduce search time for the technician by providing only the necessary and sufficient information to perform each particular maintenance task; and (3) use a medium that can be readily updated and easily stored.

With respect to its physical configuration, PEAM is a portable device (approximately the size of a briefcase) that contains the following major components, displayed in Figure 1:

1. A host controller or "electronic brain" which recognizes human speech; controls the presentation of user-requested text, graphics, and audio information; and performs automatic electronic checks of internal components to ensure that they are working properly.

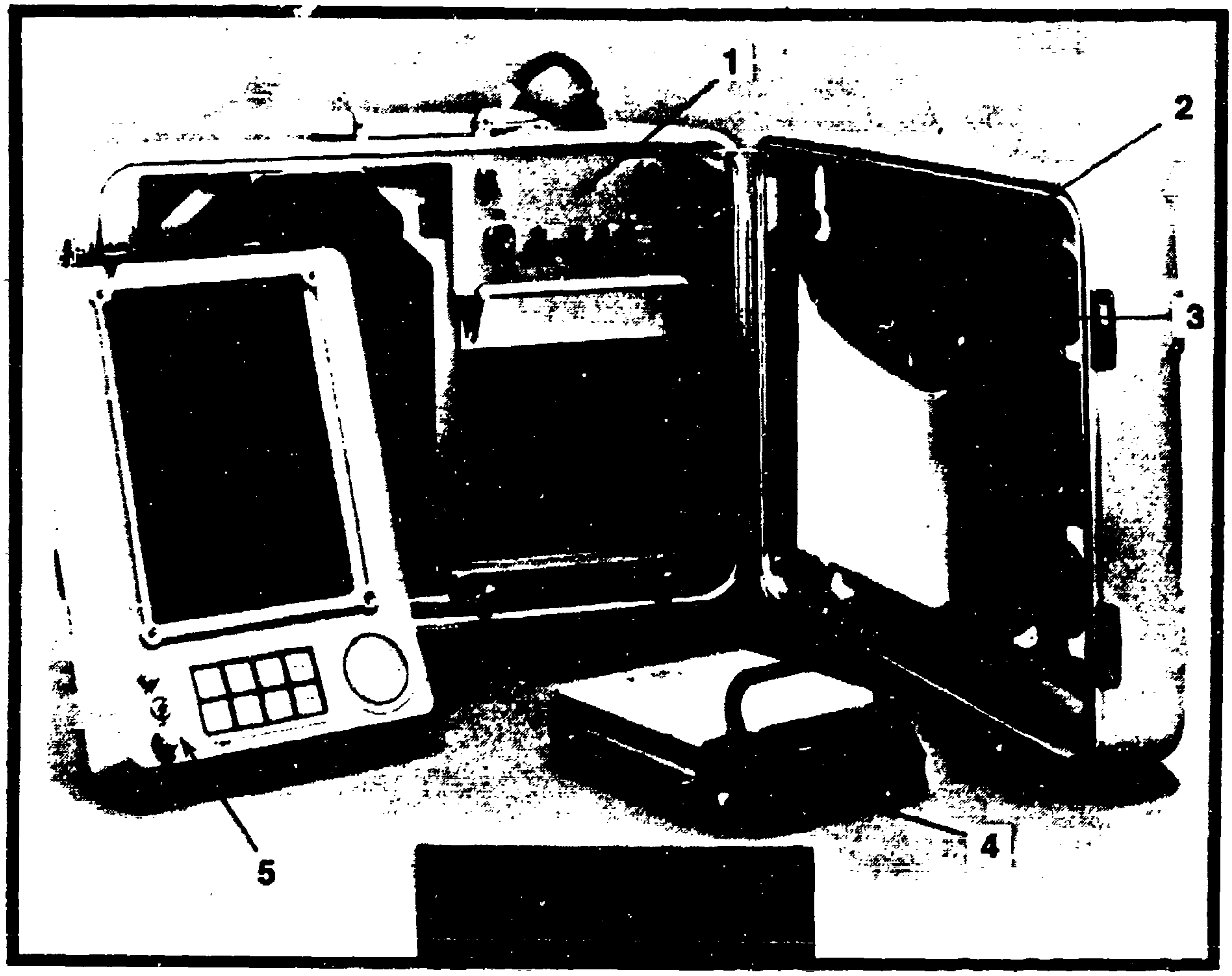
2. Power cords that link the main unit to a portable battery pack or conventional AC power sources, allowing switching between 12V DC, 28V DC, 110V AC, and 220V AC.

3. A headset with a built-in microphone and earphone that provides voice-activated cursor control/interaction with the display screen and reception of synthetic voice output, respectively.

4. A mass memory cartridge that can store approximately 175,000 words and 300 graphics. This equates to up to 4,000 narrative pages, when a data compression technique is applied.

5. A detachable interface module that can be hand-held or easily mounted. The module, which is connected to the host controller by a 12-foot long coaxial cable,

contains the following components: (a) an electroluminescent display screen, (b) an eight-function keypad, and, (c) a speaker for synthetic voice output.



1 - Host controller
2 - Power cords
3 - Headset
4 - Memory cartridge
5 - Interface module

Figure 1.
Major Components of PEAM

The PEAM interface module can present information either visually or aurally. These options can be used separately or in combination. The visual display consists of a monochrome, 5" x 7" dot matrix, thin-film electroluminescent (TFEL) panel that can display up to 350 x 490 lines (171K pixels). Textual information presented on the TFEL panel can be "read" to the user by means of a text-to-speech synthesizer. In addition, input to the device can be controlled either manually or by voice activation. The manual input consists of eight pushbutton function keys, each associated with a specific operational command (i.e., MENU, SELECT, NEXT, LAST, BACKUP, SPEAK, YES, NO). The same operational commands can be voice-activated by means of speaking into the built-in headpiece microphone. To activate this feature, the technician vocalizes each of the eight function commands several times, thereby enrolling these commands in the module's memory. When the technician speaks a command, the module performs the requested function just as if the appropriate command key had been pressed.

The structure of the PEAM database is basically hierarchical; the control starts with a top frame containing objects that link in a fixed manner with other frames. These frames, in turn, contain objects that link with other frames. A single page of a JPA, for instance, might be contained on a single frame, or be linked across several frames. The result is a database of a high degree of interconnectivity with single points of entry and multiple paths to exit. It is this early-exit feature that allows experienced technicians to traverse the database rapidly, while accommodating the less experienced technicians' requirements for detailed information review. This feature also automates the cross-referencing of information.

The database transferred to the memory module utilized a data compression scheme that allowed for the compression of up to 4,000 pages of technical documentation into one megabyte of memory. The foundation of this compression scheme relies on the fact that the vocabulary of maintenance is limited, allowing a single byte to address a look-up table of words. A frame, then, contains pointers to its constituent words which are assembled on-the-fly when a single frame is composed for display. The same concept is applied to common phrases and sentences.

Problems In Development

The development of PEAM and its databases was accompanied by numerous setbacks and impediments, as is sometimes the case in the development of a state-of-the-art prototype. There was an interruption in funding, which caused continuity problems in the contracts and extended the test and evaluation schedule. There were significant engineering challenges, especially in the connecting tolerances on the display panel, and on the design of the power supply. The satisfactory completion of the databases delayed the start of the test program, and ultimately altered the course of the evaluations. The database development process was clearly hampered by the absence of an authoring system. Simulations of PEAM on commercially available equipment were needed to complete the evaluation of the PEAM approach to maintenance. Nevertheless, there was sufficient progress on the PEAM prototypes and databases to allow a useful evaluation to proceed.

TEST AND EVALUATION

Overview

The purpose of the test and evaluation was to compare the effectiveness of PEAM to that of traditional, paper-based approaches to equipment maintenance. Since PEAM is a prototype electronic technical information delivery system, the test and evaluation was directed at general questions regarding its advantages and limitations in comparison to traditional methods of using maintenance documentation. These questions concerned accuracy in executing a maintenance prodedure, and time to complete a maintenance procedure.

Because PEAM was a joint service effort, it was evaluated in both an Army and a Navy environment. In general, each evaluation sought to determine the relative effect of PEAM on maintenance errors and time to repair. The Army evaluation used both the PEAM hardware and a commercially available, laptop-type computer with similar display features. The Army evaluation was conducted on the details of maintenance for the turret of the M1 tank. The Navy evaluation was directed at a more global level of maintenance performance on the NATO SEASPARROW Surface Missile System, and used, in effect, a simulation of PEAM on a workstation-type computer.

Each evaluation will be summarized separately; then, subsequent tables in this report will present combined results.

Army Test and Evaluation Description

The technical objective was to test PEAM on maintenance tasks in a school environment, and to compare it to technical manuals in supporting the needs of Army mechanics. The particular domain chosen for the test was tank turret maintenance for the M1 Tank. The approach involved quantitative data collection of troubleshooting performance and qualitative assessment by means of a user evaluation questionnaire. The Army test: (1) included corrective and other maintenance tasks in addition to troubleshooting tasks; (2) used the actual PEAM device as well as another portable microcomputer (a Grid Compass) which emulated the PEAM; and (3) was conducted in a simulated shop environment rather than a controlled laboratory environment. Tasks in the test included troubleshooting (6 tasks), adjust/align (3 tasks), service/maintain (2 tasks), remove (11 tasks), and install/replace (12 tasks). The test and evaluation was conducted by a contractor to the Army Research Institute.

Method

There were 14 technicians in the test, 5 in the control group using technical manuals to perform the tasks and 9 in the experimental group using PEAM or its simulator to perform the tasks. Subjects were qualified mechanics for the M60 tank turret, but not for the M1 tank turret. Each subject was observed performing tasks on a

M1 tank turret simulator or in the tank itself at the Armor School, Ft. Knox, Kentucky. A qualified instructor from the school was always available. Faults were inserted in the simulator or the tank for the troubleshooting tasks. Technicians performed each task using the tools and procedures that ordinarily are used at the Armor School.

The quantitative data were errors per task and time to complete each task. The error data included errors in good practice, errors in orientation, technique, and specification, recursive errors, and dangerous or destructive errors. The error data were summated within tasks to derivc a measure of overall average errors per task.

Navy Test and Evaluation Description

The technical objective was to test PEAM as a maintenance aid for the NATO SEASPARROW Surface Missile System (NSSMS). Specifically, this effort compared the efficiency and effectiveness of an electronically delivered technical information system to that of a paper-based documentation system in supporting the information needs of NSSMS maintenance technicians. The approach involved quantitative data collection of troubleshooting performance and qualitative assessment by means of a user evaluation questionnaire. The test and evaluation was conducted by the Navy Personnel Research and Development Center.

PEAM operational software was used to construct the electronically delivered NSSMS technical information database. Technical difficulties in loading the database onto the PEAM memory modules, however, precluded the use of PEAM hardware when tests were scheduled to be conducted. As a result, alternative hardware, a Sun 3/75 computer without a voice capability, was used to simulate the operation of PEAM. With the exception of minor differences in the method of accessing information (e.g., use of mouse control versus pushbutton function keys), the organization and format of the database were identical to that of PEAM.

Method

There were 28 participants in the evaluation, 15 instructors and 7 students from the NSSMS C-school at the Combat Systems Technical School Command in Mare Island, California, and 6 NSSMS technicians from fleet units in San Diego, California.

In the performance evaluation, the NSSMS technicians attempted to fault-isolate two problems, one using the PEAM simulation to access the required technical information, and the other using the current paper technical manuals. The faults, which were simulated on a separate microcomputer, were representative of the types of NSSMS malfunctions encountered in the fleet. In addition to troubleshooting, the technicians were required to identify specific parts of information and to locate narrative information concerning the function(s) of the circuit that contained the malfunction. Quantitative data included:

- Success criterion: successfully identifying the faulted component

- Time spent troubleshooting: overall time spent attempting to isolate the fault

- False replacements: conclusion that a component was the source of the fault when it was not

- Errors of commission: checking test points or performing tests that were unrelated to the fault symptoms

- Parts information: success in locating and time to locate the correct parts information

- Functional description: success in locating and time to locate the narrative functional description

As in the Army test, error data were summated within tasks to derive an overall measure of average errors per task.

User Questionnaire

The attitudes of test participants toward the use of PEAM were assessed by means of a user evaluation questionnaire. All 14 Army and 28 Navy participants completed the questionnaire. The questionnaire contained items relating to: (1) the physical features of the electronic delivery device (8 items); (2) the operation and software features (6 items); (3) ease of access to information (3 items); and (4) the effectiveness of the information (5 items). Open-ended comments on the likes and dislikes of PEAM were also collected.

RESULTS AND DISCUSSION

PEAM Effectiveness

Table 1 summarizes the scopes of the Army and Navy evaluations. The results of these demonstrated the potential effectiveness of electronic technical information delivery systems over conventional paper-based approaches (Table 2). These results should be interpreted with caution, however, as there were occasional differences between the databases of the technical manuals and electronic devices. These differences were due to problems in the compilation process; when they occurred, the differences were small. The small sample size in the Army evaluation leaves room for the influence of individual differences. Still, the robustness of the differences between technical manuals and electronic technical information delivery denotes the superiority of electronic delivery. There were no major differences between PEAM and its simulations.

The advantage of PEAM, in terms of error resolutions, was more pronounced for troubleshooting tasks, where a nearly 6:1 advantage was found, versus an advantage of only 2:1 for a non-troubleshooting maintenance task (Table 3). This difference is probably the result of an increase in cross-referencing and the adjunct increase in cognitive load of technicians sorting through multiple pages and volumes while trying to problem-solve a fault. Apparently, when referencing is automated, technicians can better focus their attention, which reduces the likelihood of error. Furthermore, a more detailed analysis of the Navy evaluation indicated an advantage of electronic delivery for the more complicated troubleshooting problem, in terms of number of actions required by the technicians. In the second troubleshooting problem, where the number of actions were small, the use of technical manuals was equivalent to electronic delivery in terms of errors per task.

The time factor in the Army evaluation was confounded by a slow display time exceeding 15 seconds for graphics on the PEAM device. However, in the Navy evaluation where display times on the workstation were rapid, there was nearly a 25% reduction in task completion time when using electronic delivery (Table 3).

Table 1
Scope of Army and Navy PEAM Field Tests

	Technical Manuals	PEAM/Electronic Delivery
Army		
M-1 Tank Turret	328 Task Observations 5 Subjects 220 Hours	347 Task Observations 9 Subjects 290 Hours
Navy		
NATO SEASPARROW	56 Task Observations 28 Subjects 50 Hours	56 Task Observations 28 Subjects 50 Hours

Table 2
Combined Test Results for All Tasks

	Technical Manuals	PEAM/Electronic Delivery
Average Errors/Task		
Army	1.37	.48*
Navy	5.70	.94*

Army test showed reduction in errors by nearly 3:1.
Navy test showed reduction in errors by nearly 6:1.

	Technical Manuals	PEAM/Electronic Delivery
Average Time/Task		
Army	16.4 min.	18.9 min.†
Navy	43.9 min.	33.1 min.*

* Statistically significant difference (p<.05) by parametric tests.

† Additional time for PEAM group in Army test due to long time (>15 sec. per frame) for graphics to appear.

TABLE 3
ANALYSIS OF ARMY AND NAVY TEST DATA

	Technical Manuals		PEAM/Electronic Delivery
Average Errors/Task			
		Troubleshooting	
Army	3.37		.69*
Navy	5.70		.94*
		Non-Troubleshooting	
Army	1.08		.44*

Army test showed reduction in troubleshooting errors by nearly 5:1.
Navy test showed reduction in troubleshooting errors by nearly 6:1.
Army test showed reduction in non-troubleshooting errors by nearly 2:1.

	Technical Manuals		PEAM/Electronic Delivery
Average Time/Task			
		Troubleshooting	
Army	37.0 min.		41.6 min.†
Navy	43.9 min.		33.1 min.*
		Non-Troubleshooting	
Army	12.0 min.		16.1 min.†

Note: Navy test was restricted to troubleshooting tasks.

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* Statistically significant difference ($p<.05$) by parametric tests.

† Additional time for PEAM group in Army due to long time (>15 sec. per frame) for graphics to appear.

The voice systems were, unfortunately, not given a substantive test due to technical problems. The Army test used the voice systems initially, and the users acknowledged the advantages, particularly in restricted spaces. The intelligibility, however, was not sufficiently high to maintain continual use. This advance in "hands-free" use had much intuitive appeal, but there are no direct data from the PEAM evaluations to support its use. A related project (Nugent, 1988), which would have tested the PEAM voice technology had it been available in the Navy test, found advantages in audio supplements to textual displays.

An apparent problem of the users "getting lost" in the database was noticed during the Army evaluation. There was no facility, such as an on-line map, to indicate to the user where he was in the procedure. This seemed to confuse some technicians.

Besides the empirical results, there was a collective experience gained by those involved with various phases of the project that offers a useful perspective on the development decisions that later led to problems during the test phase. Leading the list was the absence of an authoring system and format standards which resulted in labor-intensive efforts to transfer the paper-based information to digital storage. This is in sharp contrast to the current paper-based system, which is standardized to a degree through such documents as Military Specification MIL-M 3874.

The decision in 1981 to design and build a prototype rather than to acquire commercial off-the-shelf equipment was a consequence of the uncertainty at that time of the course of near-term advances in commercial developments. Given the availability of commercial equipment to simulate PEAM at the time of its evaluation, the decision remains debatable.

Questionnaire Results

Initial analysis of the user evaluation questionnaire data found no differences among the participants either in terms of their branch of service (Army or Navy) or their level of maintenance experience with either system (M-1 Abrams Tank for the Army; NATO SEASPARROW Surface Missile System for the Navy). Specifically, a multiple analysis of variance was used to analyze the mean ratings of users' responses to the four categories of questions. The results of the User Evaluation Questionnaire are summarized in Table 4.

Overall, the Navy technicians rated the electronic presentation system from "unsatisfactory" to "highly satisfactory." Although various physical characteristics were assessed in the first category of questionnaire items, a single mean (3.54) reflects the similarity in the users' ratings of those items. Similarly, the technicians rated the adequacy of the computer operation and software features in the "satisfactory" to "highly satisfactory" range (x=3.48). Use of the electronic presentation system was also perceived by the Army and Navy technicians as an improvement in terms of efficiency and effectiveness over conventional technical manuals as a source for maintenance information.

A review of the open-ended comments found that the technicians' overall impression of the electronic delivery system was generally quite favorable. The primary dislike concerned the size of the display screen for presenting schematic-type diagrams. The most frequent negative comment provided in this regard was that the diagrams were too small, thus precluding a view of the diagram in its entirety. Additional negative comments concerned the long delays encountered when the PEAM software "drew" graphic information on the screen, in some instances 15 - 90 seconds.

TABLE 4
SUMMARY OF USER EVALUATION QUESTIONNAIRE FOR COMBINED ARMY/NAVY SAMPLE

Feature	X
Physical Features	3.54
Operation & Software Features	3.48
Effectiveness of Information	3.62
Ease of Accessing Information	2.37

Scale Values:

—Physical Features:	1 = Unsatisfactory	5 = Outstanding
—Operation & Software:	1 = Unsatisfactory	5 = Outstanding
—Effectiveness:	1 = Slightly Less	5 = Significantly More
—Accessing Information:	1 = Less Difficult	5 = More Difficult

Note: Low value for Accessing Information reflects a positive response.

CONCLUSIONS AND RECOMMENDATIONS

Improvements in a technician's performance on a maintenance task can potentially be increased by electronic technical information delivery systems. Technicians are favorably disposed to their use, and they perceive improvements in effectiveness over conventional, paper-based approaches. In the conclusions and recommendations listed below, PEAM refers both to the prototype and simulations.

Findings and Conclusions

1) Use of PEAM reduced procedural maintenance errors.

2) Use of PEAM reduced time to identify corrections, except where long display times were due to equipment used in the test.

3) The PEAM approach was more effective as problems were more difficult in terms of branching and cross-referencing,

4) Users were receptive to the advantages and usability of electronic delivery.

5) Menu-driven control of a hierarchical, fixed-link Job Performance Aid (JPA) format was a successful method of procedural representation.

The first four conclusions are based on quantitative findings from the PEAM tests. The fifth conclusion is a qualitative judgment, as there was no comparison between various electronic representation formats.

Based on these findings and conclusions, and on the knowledge acquired during the course of the project, five recommendations are proposed as follows.

Recommendations

1) Future developments of electronic delivery of technical information should take into account the functional features of PEAM enhanced with the lessons learned from the test and evaluation. The features are described in Appendix A.

2) Standards for an operating system, database, and authoring system should be established prior to selection or development of delivery hardware.

3) The digitized approach to database development should be pursued in future delivery systems, as it has demonstrated advantages during development and economies in memory requirements.

4) Voice technology as an input/output medium should be considered further in future delivery systems. Its advantages were recognized by users.

5) Slow display response times negatively affected technician performance. Response times should be contained within human factors standards of about two seconds.

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Appendix A

Enhanced Functional Characteristics
Based on Lessons Learned from PEAM Test and Evaluation

Functional Characteristic	PEAM Evaluation Findings	Degree of Support from Evaluation
Screen Display		
—Size	5"x7" marginally acceptable for most applications. Exception is complex graphics such as signal flow diagrams which need larger displays (or different formats).	Medium
—Brightness (readability in day-light & dark conditions)	Screen must be light emitting. Screens without backlighting unacceptable.	High
—Resolution	70 lines per inch resolution acceptable for most applications. Complex graphics require higher resolution.	Medium
—Update Rate	Long update rate (15 sec. or greater) clearly unacceptable. Human factors guidelines are for no greater than 2 seconds.	Medium
—Function Keys	Limited set okay for field. Full keyboard desirable in shop.	Medium
Portability/ Ruggedness		
—Weight	About 27 pounds too heavy. Fifteen pounds or less acceptable. Lighter is better.	High

Functional Characteristic	PEAM Evaluation Findings	Degree of Support from Evaluation
—Size	Key to size is technicians' perception that device is portable. Size of small suitcase or attache case okay. If display is detachable, it should be made easy to hang up.	Medium
—Cables	Minimum use of cables, desirable (e.g., for microphone, power connections to weapons systems). Use radio or Infra-Red link for interactive voice.	High
—Battery Operation	4 hours acceptable for most field operations; more hours desirable.	Medium
—Power Supply	12V DC from rechargeable battery or AC converter.	Medium
—Militarized (Ruggedness)	Necessary for field operation. Not required for most shop uses. Standard microcomputer acceptable for many applications.	Low
—Interactive Voice	Interactive voice in improved form may be desirable for certain applications. Intelligibility needs improvement. Needs further study.	Medium
—Authoring System	•Development of authoring system should have high priority for follow-on work.	High
	•Automatic branching helped reduce error rate considerably (6:1 for troubleshooting).	High
	•Authoring software needs to be supported by standard operating system (e.g., MS DOS, UNIX).	High
	•Easy way to enter graphics needs development.	High

Functional Characteristic	PEAM Evaluation Findings	Degree of Support from Evaluation
	•Authoring workstation must include delivery device.	High
	•Data compression techniques worked well; should be considered for future applications if memory is a restriction.	High
	•Routines to check branching, command lines, etc., a requirement.	High
<u>Technical Information Data</u>		
—Organization/ Screen Formats	•Ease of moving through the data (for more detail or to different tasks) a mandatory feature as demonstrated. Further development of information organization techniques required.	High
	•Different levels for technician experience level is necessary for most applications.	High
	•Illustrated job aids worked well. More development needed for complex schematics such as signal flow diagrams.	High
—Training Device vs. Field Job Aid	PEAM as a job aid was tested in Army application and worked well. Feasibility of combining job aiding with training should be further considered.	High