Navy Personnel Research and Development Center

San Diego, CA 92152-6800 TN 87-41 September 1987

Troubleshooting Performance Using Paper and Electronic Documentation

DEPARTMENT OF THE NAVY
NAVY PERSONNEL RESEARCH AND DEVELOPMENT CENTER
SAN DIEGO, CALIFORNIA 92152-6800

3900
Ser 41/726
14 SEP 1987

From: Commanding Officer, Navy Personnel Research and Development Center

Subj: **TROUBLESHOOTING PERFORMANCE USING PAPER AND ELECTRONIC DOCUMENTATION**

Encl: (1) NPRDC TN 87-41

1. Enclosure (1) is submitted for your information and retention.

2. This technical note compares troubleshooting performance of maintenance technicians who used both paper-based maintenance manuals and a computerized information presentation system to obtain needed technical information. Technicians from the Navy, Marines, and Air Force participated in the study, which was an extension of an earlier one undertaken by the Air Force.

3. The research is part of the "Computer-based Aids for Troubleshooting" subproject HF008 and is a joint project under both WO542 (Human Factors Development--Aircraft) and R1771 (Human Factors Development--Ships) as part of program element 63701N, Human Factors Advanced Development.

4. Comments and recommendations regarding this report are welcome. Navy Personnel Research and Development Center point of contact is Dr. Robert J. Smillie, Combat Systems Division, (619) 225-6617 or AUTOVON 933-6617.

RICHARD C. SORENSON
By direction

Distribution:
Assistant Secretary of Defense (Force Management and Personnel)
Deputy Under Secretary of Defense for Research and Engineering (Research and Advanced Technology)
Military Assistant for Training and Personnel Technology (OUSD) (R&AT)
Assistant Secretary of the Navy (Manpower and Reserve Affairs) (OASN) (M&RA)
Deputy Chief of Naval Operations (MP&T) (OP-01)
Assistant for MPT Research and Development and Studies (OP-01B7)
Research and Development Coordinator (OP-111J2)
Director, Military Personnel Policy Division (OP-13)
Director, Human Resources Management (OP-15)
Deputy Chief of Naval Operations (Logistics) (OP-04)
Director, Joint and Operational Logistics, Plans and Programs Division (OP-40B), (OP-431)
Assistant for Manpower, Personnel, and Training (OP-983D)
Commander, Naval Sea Systems Command
Commander, Naval Supply Systems Command
Commander, Space and Naval Warfare Systems Command (SPAWAR-00)
Deputy Commander (SPAWAR-10)
Director of Navy Laboratories (SPAWAR-005)

Commander, Naval Air Systems Command
Commander, David W. Taylor Naval Ship Research and Development Center
Commander, Naval Air Development Center
Commanding Officer, Naval Training Systems Center
Commander, Naval Weapons Center
Director, Office of Naval Research (OCNR-10)
Commander, U.S. ARI, Behavioral and Social Sciences, Alexandria, VA (PERI-POT-I)
Technical Director, U.S. ARI, Behavioral and Social Sciences, Alexandria, VA (PERI-ZT)
Director, Army ATCO, Ft. Eustis, VA
Commander, Air Force Human Resources Laboratory, Brooks Air Force Base, TX
Commander, Air Force Human Resources Laboratory, Manpower and Personnel Division, Brooks Air Force Base (AFHRL/MO), Scientific and Technical Information (STINFO) Office
Commander, Air Force Human Resources Laboratory, Wright-Patterson Air Force Base, OH, Logistics and Human Factors Division (AFHRL/LRS-TDC)
Institute for Defense Analyses, Science and Technology Division
Defense Technical Information Center (DTIC) (2)

NPRDC TN 87-41 September 1987

Troubleshooting Performance Using Paper and Electronic Documentation

William A. Nugent
Stephen I. Sander
Duane M. Johnson
Robert J. Smillie

Approved for public release;
distribution is unlimited.

Navy Personnel Research and Development Center
San Diego, California 92152-6800

SUMMARY

Problem

The increasing complexity and sophistication of modern weapon and support systems are resulting in massive volumes of technical operation and maintenance information. Electronic information delivery holds potential for rapid access to needed information stored on compact memory units. There have been only limited comparisons, however, between the effectiveness and efficiency of electronic information delivery and conventional paper-based technical manuals.

Objective

The objective of this study was to extend the results of an earlier Air Force study and compare the troubleshooting performance of military technicians who obtained information from conventional, paper-based maintenance manuals and from electronic devices.

Procedure

Four troubleshooting tasks were administered to 36 technicians, 12 each from the Air Force, Navy, and Marine Corps. The tasks consisted of identifying a fault introduced into a circuit relay or discrete component on a printed circuit card used in the RT-728A/APX-64(V) radio receiver transmitter. Two tasks were performed using conventional manuals and two using information presented on a GRiD Compass II computer. Presentation combinations were balanced to avoid experimental bias. Independent variables of technician experience level and information delivery method were arranged in a 2 x 2, between-subjects multiple analysis of variance (MANOVA) design. Dependent variables included measures of time and efficiency. User evaluations were obtained by means of questionnaires and structured interviews.

Results

Significant differences were found with regard to time to identify faulted card, total problem solution time, and number of false item replacements, all of which were less for electronic than for conventional information delivery. Significant differences were also found with regard to number of test points checked, total number of tests performed, and number of problems solved, all of which were greater for electronic than for conventional information delivery. Thus, with electronic information delivery, technicians performed more thorough and successful troubleshooting in less time. Technician evaluations of electronic information delivery were also consistently favorable. The only major criticism of the computer concerned the inadequacy of screen size for displaying schematics.

Conclusion

Electronic information delivery can be an effective and efficient means of presenting technical maintenance information. To date, however, most research has involved only limited data bases. Future research needs to address the effects of large technical data bases and the various ways of accessing the different types of information in those data bases.

CONTENTS

LIST OF TABLES

INTRODUCTION

Problem

With the growing complexity of military systems, there is a concomitant increase in the volume of technical information needed for their operation and maintenance. For example, today's F/A-18 Hornet aircraft requires approximately 500,000 pages of technical documentation compared to 1,800 pages for a jet fighter aircraft introduced in 1950.

One method for coping with increased equipment complexity and the amount of technical information supporting it has been the assignment of technicians with different types of training and experience to individual subsystems within a major system such as an aircraft. Unfortunately, since the population from which available technicians are drawn is decreasing (Binkin, 1986), it will not be effective to have technicians specialize in single systems or subsystems in the future. Rather, quick access to accurate technical information by all technicians will be a necessity for the maintenance of modern weapon systems.

Electronic presentation techniques offer an approach to quick access of technical information. The Department of Defense recognizes this in calling for the "extensive study of user interaction with non-paper maintenance aids" and "research, experimentation, and field trial experience . . . to find out what form of displays are best for specific situations" (Riddell, Gunkel, Beiser, Goldstein, & Lepisto, 1985). Of critical interest is the effectiveness of using non-paper maintenance aids and displays for quick access to technical information for fault isolation. While the Air Force has demonstrated the feasibility of electronic delivery of technical information (Clay, 1986), performance data comparing the effectiveness and efficiency of electronically presented information to those of the conventional paper technical manuals have been limited.

Objective

The objective of this study was to extend the results of an earlier Air force study and compare the troubleshooting performance of military technicians who obtained information from conventional, paper-based maintenance manuals and from electronic devices.

Background

The present effort is part of a larger research and development project titled "Computer-based Aids for Troubleshooting (CBAT)." The goal of CBAT is to design and evaluate electronic presentation techniques to ensure that required troubleshooting information is readily available to, and accessible by, the technician during corrective maintenance. The present evaluation was an extension of an earlier Air Force Human Resources Laboratory (AFHRL) study in which electronic presentation of technical information was used to support isolation of a single fault (Clay, 1986).

In the AFHRL study, a prototype computer-based maintenance aid system (CMAS) was developed to evaluate technical data presentation and user interface techniques. An off-the-shelf computer was used as the prototype delivery device. Software was developed to store and present technical information in an integrated text/graphics format. A preliminary evaluation of this data base was accomplished by having eight Air Force technicians perform assigned maintenance tasks using technical information presented via CMAS. In general, the technicians expressed positive comments about the use of CMAS to support maintenance. Since the primary purpose of the AFHRL study was to demonstrate the concept of electronic delivery of technical information, only limited data were obtained comparing CMAS to conventional technical manuals in isolating a fault.

While several studies have examined effects of technician experience level on the use of different methods for presenting technical information (e.g., Elliott & Joyce, 1971; Serendipity, Inc., 1969), the impact of this variable when using electronic presentation as an alternative to the paper-based technical manual has not been sufficiently researched. The results from the present study will be used in conjunction with those from the AFHRL study to document the advantages and disadvantages of electronic delivery of technical information for both experienced and inexperienced maintenance personnel.

APPROACH

Test Vehicle and Troubleshooting Tasks

The RT-728A/APX-64(V) radio receiver-transmitter, which served as the test vehicle for the AFHRL study, was also used as the test vehicle in the present effort. This equipment provides ground-based control centers with aircraft location, altitude, and identification (friend or foe) data. As shown in Table 1, the RT-728A/APX-64(V) is currently installed in a variety of Navy, Air Force, and Marine Corps aircraft.

Table 1

Use of the RT-728A/APX-64(V) by Navy/Marine Corps/
Air Force Aircraft

Navy	Marine Corps
CH-53 A&D	CH-53 A&D
A-4F	OA-4M
EA-4F	OV-1DA
A-6B (Reserves)	OV-1DD
T-2B & C	
7A-7C	**Air Force**
TA-4F	
TA-4J	B-52
	KC-135
	C-137
	H-3
	CH-53

Four RT-728A/APX-64(V) printed circuit card failures were used as troubleshooting problems in the present effort. Of these, one was identical to that used in the AFHRL study. The remainder were chosen with the assistance of senior RT-728A/APX-64(V) maintenance instructors at the Naval Air Maintenance Training Group Detachment 1028 in Tustin, California.

The printed circuit card malfunctions were introduced by faulting circuit relays or discrete components. Additionally, precautions were taken to ensure that (1) the faulted components could not be easily identified on the basis of visual inspection alone, (2) the casualty symptoms/failure indications for any given problem were consistent upon successive administration of the problem, and (3) sufficient information was available from both the automated system and the current RT-728A/APX-64(V) technical manual for isolating each printed circuit card failure to the component level.

Technical Information Delivery Systems

The two delivery methods used to present fault detection and fault isolation information were the technical manual for the RT-728A/APX-64(V) and an off-the-shelf computer with an expanded version of the AFHRL CMAS technical information data base.

The computer was a GRiD Compass II, model 1139.[1] The GRiD was used in the earlier AFHRL study because of its small size and powerful capabilities. Since the operating system software and the available data base were somewhat uniquely tailored to the GRiD, the newly developed material was added to the existing data base.

AFHRL had developed the software to store and present technical manual data on the GRiD. Functions provided by the software included: (1) scrolling to portions of a diagram too large to be displayed on the screen, (2) direct access to parts of the data base without using menus, (3) automatic branching to a specific kind of information after a decision had been made, (4) display of available options, and (5) availability of two levels of detail for

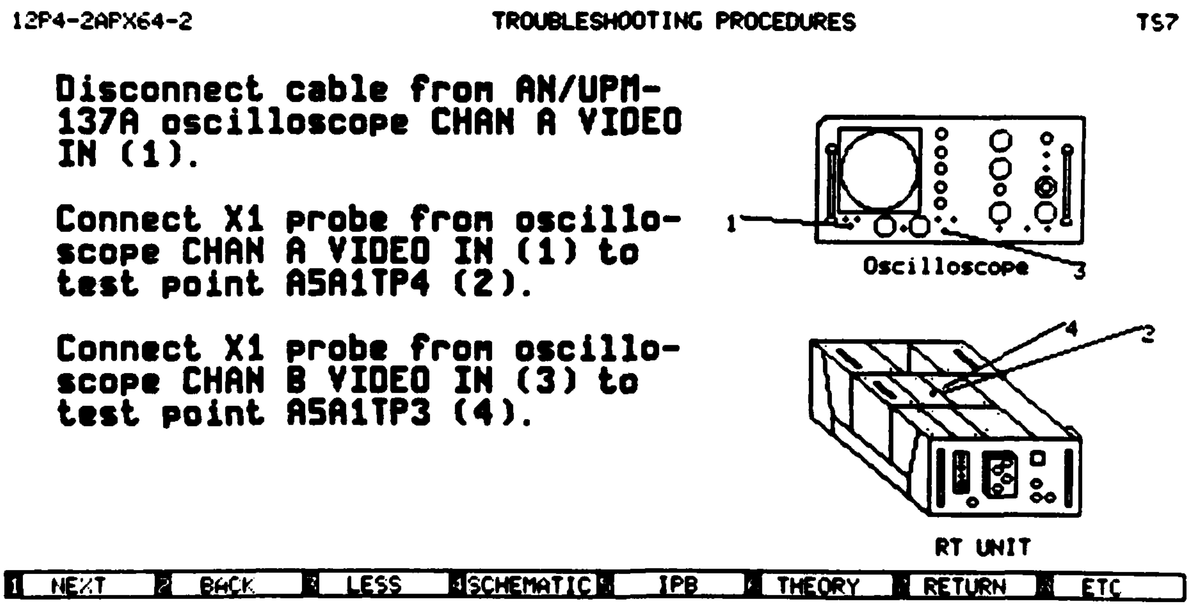

Figure 1. An example of the integrated text/graphics format of the electronic data base. The MORE level of detail is presented here.

[1]Identification of the equipment is for documentation only and does not imply endorsement.

procedural information. The general structure of the electronic data base was an integrated text/graphics format, as shown in Figure 1. As stated, procedures in the electronic data base were developed for two levels of detail. The MORE level contained detailed text descriptions along with supporting graphics. The LESS level was an abbreviated version of MORE, a checklist with less detailed graphics. MORE was designed for inexperienced technicians, while LESS was intended for more experienced personnel.

Changes to the original CMAS data base included (1) additional schematic diagrams, (2) detailed, illustrated parts breakdown information, and (3) troubleshooting procedures necessary to cover the four problems. These changes were developed and validated with the assistance of RT-728A/APX-64(V) maintenance technicians at the Air Intermediate Maintenance Department, Naval Air Station, North Island, in San Diego, California.

Participants

Thirty-six RT-728A/APX-64(V) technicians for the Air Force, Marine Corps, and Navy assigned to four intermediate-level avionics maintenance facilities in California served as participants. Six of the 12 Marine Corps technicians were from Headquarters and Maintenance Squadron-13, Marine Corps Air Station in El Toro; the remainder were from Headquarters and Maintenance Squadron-16, Marine Corps Air Station in Tustin. The 12 Air Force technicians were assigned to the 93rd Avionics Maintenance Squadron, Castle Air Force Base in Merced. The 12 Navy technicians were assigned to the Air Intermediate Maintenance Department, Naval Air Station, Miramar, in San Diego.

Since level of experience has been shown to have an effect on performance (Serendipity, Inc., 1969), the participants at each facility were classified into two groups consisting of equal numbers of experienced and inexperienced technicians. Group assignment was based on a combination of relevant field experience in the maintenance of the RT-728A/APX-64(V) (i.e., 1 or more years for the experienced group; less than 1 year for the inexperienced group), and judgments of immediate work supervisors concerning the technician's maintenance qualifications.

Participation in the testing was voluntary. No one declined to participate, and all participants appeared interested and cooperative throughout the test sessions.

Procedure

A detailed test administrator's guide was prepared to standardize the presentation of instructions and troubleshooting problems to all participants. The following sections summarize the procedures used in each test session.

Preliminary Instructions and Procedures

The participants were tested individually and sat at a workbench that contained the necessary tools, equipment, and technical information delivery systems. Instructions were read aloud to the participants to provide them with a general orientation to the testing and data collection methods. Procedures for maintaining the technician's anonymity and voluntary participation in the testing were described, followed by a set of questions regarding each participant's background.

Since the technical information needed to solve all four problems was available in both delivery methods, each participant was randomly assigned to a four-problem set that counterbalanced order of presentation and delivery method. Each participant then received instructions on the basic operation of the automated technical information delivery system and was given an opportunity to practice on it. Upon completion of the preliminary instructions and procedures, which averaged 30 minutes, participants were given a short rest break.

Problem Administration

Each troubleshooting problem began with a brief description, read aloud, of the major casualty symptom (or, in technician's jargon, "gripe") associated with the printed circuit card failure. This information was followed by the identification of a specific "start point" in the technical manual or the computer data base from which the participant was to initiate troubleshooting actions. In addition, participants were informed that the test administrator would only provide information to them regarding: (1) expiration of the time allowed for completing each problem, (2) whether a printed circuit card or module they recommended for replacement would or would not correct the failure, or (3) actions needed to extricate themselves from difficulties encountered when branching through the computer data base. Participants were given a short rest break between each troubleshooting problem.

Debriefing

The test session, which lasted an average of 4 hours per technician, ended with a discussion of the purpose of the study together with a general review of performance on the problems. The technicians were then thanked for participating and asked to refrain from discussing details of the study with others who had not yet been tested.

Data Collection Forms

Three basic forms were used to record the performance and attitudes of the participants.

Performance Observation Forms. These forms were used by the test administrator to obtain both general and highly specific performance data. A "general-purpose" form provided spaces for problem start and stop times, particular options used in the computer data base, and other information related to test problems. Additional space was provided on this form for recording observations and comments. Two supplemental forms were used for recording the particular troubleshooting path followed by the participant if he/she succeeded in localizing the fault to the affected module and card.

User Questionnaire. A user evaluation questionnaire was administered to each participant. It had three sections: (1) rating of physical features of the computer; (2) evaluation of information presentation by the computer, and (3) comparison of the presentation modes. The section on physical features contained questions on the GRiDs keys, display, graphics, and scrolling features. The focus of the section on information presentation was adequacy and ease of use. In the last section, the technician compared the computer presentation mode to the paper mode (Appendix A).

Structured Interview. In addition to the ratings obtained from the user questionnaire, open-ended comments and reactions from the participants were recorded by the test administrator on a structured interview form. The first four items dealt with various features of the computer data base and the next four addressed the users' likes and dislikes concerning the use of the prototype electronic delivery device for supporting corrective maintenance. Spaces were also provided on this form for recording any additional comments by the participants (Appendix B).

Experimental Hypotheses and Design

The following hypotheses served as the framework for comparing performance using the two methods of presenting technical information.

1. Troubleshooting will take less time using the electronic presentation system than using technical manuals.

2. Fewer tests will be performed using the electronic presentation system than using technical manuals.

3. Fewer unnecessary replacements (modules and circuit cards) will be made using the electronic presentation system than using technical manuals.

4. More faults will be isolated successfully using the electronic presentation system than using technical manuals.

5. Inexperienced technicians using the electronic presentation system will troubleshoot as well as experienced technicians using technical manuals.

6. When using paper-based technical manuals, experienced technicians will troubleshoot better than inexperienced technicians.

7. Performance differences will be greater between the two presentation methods for inexperienced than for experienced technicians.

The independent variables of technician experience level and technical information presentation method were arranged in a 2 X 2, between-subjects multiple analysis of variance (MANOVA) design. The dependent measures were:

1. Time to isolate the failure to the printed circuit card level.

2. Time to isolate the failure to the faulted component level.

3. Overall time to problem completion.

4. Number of external test points checked (i.e., test points accessible without removing modules or printed circuit cards from the unit).

5. Number of discrete components checked on the printed circuit card containing the fault.

6. Total number of fault isolation tests performed.

7. Number of false replacements recommended to correct the failures (i.e., a participant's recommendation for a replacement of an RT-728A/APX-64(V) module or printed circuit card that was functioning correctly and would not correct the failure).

8. Number of printed circuit card failures successfully isolated.

RESULTS

Demographic Comparisons

Preparatory to the tests of the experimental hypotheses, analyses were conducted to determine the extent to which the two groups of participants differed in terms of responses to items contained on a personal background form. These analyses were performed to provide quantitative evidence that the two groups did differ on variables relevant to experience and also to determine if any demographic factors warranted inclusion as covariates in subsequent data analyses. The two groups were compared according to: (1) number of enlisted occupational specialties held, (2) months in service, (3) current enlisted pay grade, (4) years of civilian education completed, (5) prior civilian schooling/training in electricity or electronics, (6) prior civilian work experience in electricity or electronics, (7) prior training/experience in operating computers, (8) type of RT-728A/APX-64(V) maintenance training received (formal versus on-the-job), and (9) months of experience in the maintenance of the RT-728A/APX-64(V).

The two groups differed significantly on three variables relevant to experience: The experienced technicians had a higher enlisted pay grade (4.8 versus 3.5), longer time in service (67.4 versus 44.2 months), and had more months of RT-728A/APX-64(V) maintenance experience (33.4 versus 2.8 months) than the inexperienced group. Because no reliable group differences were obtained for the remaining variables, inclusion of these as covariates in subsequent analyses was not considered.

Performance Analyses

It should be noted that 9 of the 36 participants failed to isolate the faulted component on one or both troubleshooting problems administered when using maintenance manuals. For that reason, data points were not available from these nine participants with respect to the faulted component time and test measures. In each case the troubleshooting session was terminated due to time limitations imposed by the testing schedule. (A 1-hour time limit was allowed for isolating the casualty to the affected printed circuit card. If this criterion was met, an additional 15-minute time period was allowed to isolate to the component level; otherwise the session was terminated.) The absence of data points for these two measures also precluded the use of the overall time and the total number of fault isolation tests for these 9 technicians. Consequently, a decision was made to analyze the performance data in two ways. The first MANOVA included four of the eight categories of outcome measures for the entire sample of 36 technicians tested. The second MANOVA included seven categories of outcome measures obtained from the sample of 27 technicians who successfully completed all troubleshooting problems. (The number of problems solved was excluded from the latter analysis since this measure had no variance.) Results from each of these MANOVAs are presented in the following sections.

Overall Sample

Contrary to predictions concerning the experience factor and presentation method (hypotheses 5-7), no significant interactions were found in the results of the first MANOVA ($N = 36$). In addition, the main effect for experience was also nonsignificant. Only the main effect for presentation method was significant: $F(4, 65) = 16.28$, $p < .01$, supporting hypotheses 1, 3, and 4. The difference in the number of tests performed under each method of presentation was also significant, but the result was the opposite of the stated hypotheses, that is, there were more tests using the electronic presentation system. Table 2 provides a detailed breakdown of the performance differences attributed to the presentation method.

Table 2

Performance Difference Resulting from the Use of Technical Manuals Versus the Use of the Electronic Presentation System for the Overall Sample (N = 36)

Measure	$\bar{X}$ Technical Manual	$\bar{X}$ Electronic Presentation	$F(1, 68)$	p
Time to faulted card (min.)	56.5	24.4	35.72	.01
Test points checked	3.6	5.6	12.90	.01
False replacements	1.2	0.0	25.96	.01
Problems solved	1.7	2.0	9.90	.01

Reduced Sample

Results from the second MANOVA (n = 27) mirrored the first; only the main effect for presentation method was significant: $F(4, 65) = 8.77$, $p < .01$. Results are shown in Table 3.

Table 3

Performance Difference Resulting from the Use of Technical Manuals Versus the Use of the Electronic Presentation System for the Reduced Sample (n = 27)

Measure	$\bar{X}$ Technical Manual	$\bar{X}$ Electronic Presentation	$F(1, 50)$	p
Time to faulted card (min.)	45.6	22.4	20.77	.01
Time to faulted component (min.)	28.5	22.6	3.99	.06
Total time to solution (min.)	74.1	45.0	20.56	.01
Test points checked	3.5	5.0	13.31	.01
Components checked	8.8	11.5	3.86	.06
Total tests performed	12.3	16.5	8.34	.01
False replacements	0.8	0.0	11.79	.01

User Evaluation Questionnaire

The results from the 31 items in the User Evaluation Questionnaire are shown in Table 4. The overall response to the computer was "highly satisfactory" or "outstanding." Although four physical characteristics were assessed, a single mean (3.95) is shown for items 1 through 16 to reflect the similarity in evaluation of the four characteristics. Each of the 16 items was consistently rated "highly satisfactory" or "outstanding." A single exception was the evaluation concerning the adequacy of the screen size, which was rated as "satisfactory" ($\bar{X} = 3.2$). The adequacy of the technical information presented on the computer and of access to that information was rated "highly satisfactory" ($\bar{X} = 4.22$). Use of the computer was perceived as an improvement in terms of efficiency and effectiveness over the RT-728A/APX-64(V) manual for troubleshooting.

Table 4

Summary of User Questionnaire Evaluation

Feature	Questionnaire Items	$\bar{X}$
Physical characteristics	1 - 16	3.95[a]
Information presentation	17 - 24	4.22[a]
Efficiency	25 - 27	1.68[b,c]
Effectiveness	28 - 31	4.38[b]

[a]Scale values: 1 = unsatisfactory, 5 = outstanding.

[b]Scale values: 1 = significantly less, 5 = significantly more.

[c]The low mean for items 25 - 27 is a positive response.

No differences were found between the ratings of experienced and inexperienced technicians. Differences in the evaluation of the computer were obtained, however, between technicians on the basis of previous civilian work experience in electricity or electronics. Specifically, technicians with no previous work experience provided a higher overall rating of the automated system ($\bar{X} = 4.3$) than did technicians who had prior civilian work experience in electricity or electronics ($\bar{X} = 3.8$).

Structured Interview

A summary of the results of the 36 technician interviews is shown in Table 5. No data are shown for interview items 1, 2, 4, 8, and 9, because few, if any, responses were made to these items. Responses from all participants are combined since no differences were found between the services or between experience levels.

Table 5

Summary of Interview Responses

Item	Response	n	Percent
#3: Level of detail			
a. Ease of switching	Yes	31	86
b. Two levels sufficient	Yes	34	94
c. Preference	LESS	9	25
	MORE	14	39
#5: Likes about GRiD	Quick/easy access to information	15	42
	Proceduralized: easy to go from one point to another	12	33
	Deletes excessive narrative; direct path to fault	9	25
	Reduces troubleshooting time	8	22
	Ease in switching among frames	7	19
#6: Dislikes about GRiD	Schematic: cannot see entire schematic on the screen	17	47
#7: Mode preference	GRiD	27	75
	Paper	1	3
	Both	7	19

Level of Detail (Item #3)

Technicians assigned high value to the provision by the computer of two levels of detail and to the ease with which they could switch back and forth between levels. Experienced and inexperienced technicians generally showed no difference in their preference for more or less detail, even though less detail was suggested as better for simple, proceduralized tasks and for faster troubleshooting and more detail was suggested for finding parts and for providing extra information to the inexperienced technicians.

Likes and Dislikes of the Computer (Items #5 & #6)

The six comments shown in Table 5 express the scope of the like-dislike comments about the GRiD and account for 95 percent of all comments provided. A general theme was that the computer was more efficient and effective in providing information needed to troubleshoot the faulted printed circuit cards. The primary dislike concerned the presentation of schematics. The most frequent comment provided in this regard was that schematics were too small (i.e., precluding a view of the schematic diagram in its entirety).

Mode Preference (Item #7)

The computer was preferred by 75 percent of the technicians for supporting fault isolation. Nineteen percent of the technicians expressed preference for both methods of delivering technical information. The rationale offered by technicians who preferred both delivery systems was that the technical manual would be used when referring to circuit schematics; otherwise the computer would be used to support them during performance of corrective maintenance actions. Three percent of the technicians indicated that information regarding functional descriptions and theory of operation was more adequately presented in the RT-728A/APX-64(V) technical manual.

DISCUSSION

The electronic presentation method improves troubleshooting performance. Using the electronic presentation method, technicians took less than half the time to isolate the faulted card, made no false replacements, and solved all the problems. These findings were consistent with hypotheses 1, 3, and 4. Concerning the second hypothesis, more rather than fewer tests were performed when participants used the computer.

In formulating the second hypothesis, we assumed that the more effective troubleshooting strategy would be one that incorporated fewer tests (all tests being relatively equal), and only the logic in devising the sequence of tests would differ. When using the paper-based technical manual, the technician had to rely on deductive reasoning to determine where and what type of test point to check. Presumably, the technician pursued a troubleshooting strategy that provided the most information related to a given symptom. With the electronic presentation format, on the other hand, troubleshooting was more directive, that is, once a test was selected and the results entered into the computer, the computer automatically branched to the next logical test (derived from subject matter experts' analyses of the fault) in the fault isolation procedure related to the given symptom. Results demonstrated that even though technicians using the electronic presentation method made more tests, the time to correctly identify the faulted card was significantly less.

The failure of the experience level variable to account for any appreciable variance in the outcome measures when using the electronic presentation method is consistent with previous research findings. For example, Foley and Camm (1972) found that when inexperienced technicians were given detailed, step-by-step maintenance and troubleshooting procedures, they performed as well and with fewer errors than more experienced technicians performing the same tasks as they normally would (i.e., with or without using conventional maintenance manuals). More recent evidence to support the present findings was obtained in the AFHRL maintenance demonstration described previously (Clay, 1986). This study found no difference in the time required for experienced and inexperienced Air Force technicians to perform an RT-728A/APX-64(V) calibration task or to isolate a faulted component on one of its printed circuit cards when using the computer.

It is somewhat harder to explain the failure of the experience level variable to account for any appreciable variance in the outcome measures when participants used the RT-728A/APX-64(V) maintenance manual. Two possible factors may have produced these findings. First, while results indicate a clear-cut difference between groups with respect to the average amount of RT-728A/APX-64(V) experience, no controls were imposed on the recency of that experience. Thus, for example, some technicians had 3 years of relevant maintenance experience but none within 3 years prior to the testing! In fact, many of the experienced technicians claimed to be "rusty" when it came to working on the RT-728A/APX-64(V), a factor that may have put them on par with the less experienced technicians.

Another possible explanation has to do with the particular controls imposed during the test sessions to ensure standardization in the troubleshooting approaches used by participants. For example, participants were told the specific location in the maintenance manual from which they were to initiate troubleshooting actions and were also instructed to inform the test administrator when they wanted to replace suspected faulty modules or printed circuit cards with known good ones. Because of this structure imposed on the problems, participants may have been precluded from using their own individual approaches to isolating the failures, thereby diminishing any differences in performance that might otherwise have been demonstrated by their experience levels.

Results from both the user questionnaires and structured interviews indicate that the concept of electronic delivery of technical information is an acceptable alternative to the paper-based maintenance manual. All the technicians reacted favorably towards the electronic presentation of technical information. Using the paper-based manual, technicians had to search for some of the fault isolation information. With the directive nature of the electronic presentation, however, the search behavior was ameliorated. Although resistance to change was not specifically addressed in this study, the overall positive response was indicative of how such an innovation could be introduced into the field. In fact, no technicians expressed any concern about the electronic and mechanical reliability of the computer compared to the omni-reliable, paper-based technical manual.

The only major criticism of the computer concerned the inadequacy of the schematic presentation on the computer display screen. It is interesting to note, however, that most technicians did not refer to the schematics when using the computer. Had the technicians elected to use these schematics during the test sessions, it is possible that they may have evaluated them more positively, as was reported by Clay (1986).

CONCLUSIONS

In summary, the results demonstrate that computers can be used as an effective means to present technical information in an electronic format. If the technical information data base is constructed for ease of access, as was that for the RT-728A/APX-64(V), maintenance performance should improve. More importantly, technicians appear willing to change to a different delivery method for obtaining maintenance information.

Since the data base was very limited in the present effort, future evaluations need to address extremely large technical information data bases that offer many ways of entering and branching to the various types of information within those bases.

REFERENCES

Binkin, M. (1986). Military technology and defense manpower. Washington, DC: The Brookings Institution.

Clay, J. D. (1986). Development of computer-based maintenance aid system. Wright-Patterson Air Force Base, OH: Air Force Human Resources Laboratory.

Elliott, T. K., & Joyce, R. P. (1971). An experimental evaluation of a method for simplifying electronic maintenance. Human Factors, 13, 217-227.

Foley, J. P., Jr., & Camm, W. B. (August 1972). Job performance aids research summary. Wright-Patterson Air Force Base, OH: Air Force Human Resources Laboratory. (AD 697-034)

Riddell, F. R., Gunkel, R. A., Beiser, G., Goldstein, S., & Lepisto, B. (June 1985). Report of the joint industry-DoD task force on computer aided logistic support (CALS): Vol. I. Summary (IDA Report R-285). Alexandria, VA: Institute for Defense Analysis.

Serendipity, Inc. (May 1969). Project PIMO final report: PIMO final report summary (TR-69-155, Vol. I). Norton Air Force Base, CA: Space and Missile Systems Organization, Air Force Systems Command. (AD 852-101)

APPENDIX A

USER EVALUATION QUESTIONNAIRE

Reference Code ________

USER EVALUATION QUESTIONNAIRE

Introduction

The electronic information delivery device you used for two of your troubleshooting tasks is one example of how technical information may be delivered in the future. Since you and other technicians may eventually be using such a device, your reactions and comments are important.

Evaluate the questionnaire items using the 5-point scale appearing to the right of the items. Rate each item by placing an "X" in the appropriate column. Respond to as many of the questionnaire items as possible but recognize that there may be some items you cannot evaluate based on your limited experience with this device. In those cases, place an "X" in the column head "Can't Evaluate."

A: Physical Features

Items	Scale Values					
	Unsatisfactory	Marginal	Satisfactory	Highly Satisfactory	Outstanding	Can't Evaluate
1. Location of keys.						
2. Spacing of keys.						
3. Ease of operating keys.						
4. Indication (feedback) that keys had been activated.						
5. Reliability of keys (i.e., Did GRiD respond appropriately to the keys you pressed?).						
6. Response time after keys.						
7. Adequacy of screen size for displaying information.						
8. Spacing of information on the display screen (i.e., lack of clutter/crowding).						

Reference Code ________

Items	Scale Values					
	Unsatisfactory	Marginal	Satisfactory	Highly Satisfactory	Outstanding	Can't Evaluate
9. Brightness of display.						
10. Contrast between information on the display and background.						
11. Glare on display.						
12. Legibility of displayed letters and words.						
13. Format/arrangement of graphic displays (e.g., schematic, block diagrams, IPBs).						
14. Resolution and clarity of graphic displays.						
15. Adequacy of detail on graphic displays.						
16. Adequacy of scrolling feature.						

Reference Code ________

B: Information Presentation

Items	Unsatisfactory	Marginal	Satisfactory	Highly Satisfactory	Outstanding	Can't Evaluate
17. Adequacy of the organization and arrangement of maintenance information						
18. Adequacy of options available on menus.						
19. Ease of using menus to obtain different types of maintenance information (e.g., procedural steps, schematics, IPBs).						
20. Ease of obtaining specific information within a particular type of maintenance information (e.g., locating a specific part in the IPB).						
21. Ease of obtaining more/less detailed information.						
22. Adequacy of illustrations used to supplement text or procedures.						
23. Adequacy of information for supporting maintenance tasks (i.e., completeness, accuracy, relevancy).						
24. Ease of using menus to return to the appropriate place in a set of procedures after branching elsewhere to obtain additional information or details.						

Scale Values apply to the six rating columns.

Reference Code ________

C: Comparatiave Assessment
(Electronic versus Paper Documentation)

This section of the questionnaire deals with the efficiency and effectiveness of the GRiD computer as compared with current maintenance documents for the APX-64. The words listed under the heading "scale values" have changed. Please review this scale carefully before rating the items.

To avoid repetition in the wording of the items contained in this section, begin each with the phrase:

Compared with using current maintenance documents for the APX-64, how would you rate the computer version in terms of . . .

Items	Scale Values: Significantly Less	Slightly Less	No Difference	Slightly More	Significantly More
25. The time and effort required to change from one type of maintenance information to another (e.g., moving from procedures to the parts information).					
26. The time and effort required to obtain more detailed information for a particular maintenance action or step.					
27. The overall time and effort required to perform fault isolation.					
28. The extent to which it represents improvement in the overall organization and arrangement of maintenance information.					
29. The ecxtent to which it represents improvement in the presentation of maintenance information.					
30. The extent to which it represents improvement in the overall completeness, accuracy, and applicability of maintenance information.					
31. The extent to which it represents improvement in supporting maintenance for the APX-64.					

APPENDIX B

STRUCTURED INTERVIEW

Reference Code ______

STRUCTURED INTERVIEW

Based upon the degree of use of the following features--

scrolling
schematics
switching between levels of detail

--ask the following:

		Yes	No
1.	If scrolling was used:		
	a. Was it useful?	___	___
	b. Was it easy to use?	___	___
	c. Comments: ______________________		
2.	If schematics were used:		
	a. Were they easy to use?	___	___
	b. Comments: ______________________		
3.	If more than one level of detail was used:		
	a. Was it easy to switch between levels?	___	___
	b. Were two levels of detail sufficient?	___	___
	c. Which level did you prefer?	________	
	d. If no to "b," how many levels should there be?	________	
	e. Why?		
	f. Comments: ______________________		

Reference Code ________

4. If no switching between levels of detail was done:

   Why?

Ask the following questions:

5. What did you like about using the GRiD personal computer for maintenance information?

6. What did you not like about using the GRiD personal computer for maintenance information?

7. If you had the choice, what would you use to support fault isolation:

   GRiD personal computer ________

   Paper technical manual ________

   Why?

8. What would you do to improve the way maintenance information is presented on the GRiD computer?

9. Additional comments: