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WILLIAM R. TAUZEL,
Colonel, USAF
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EXECUTIVE SUMMARY

Purpose

The purpose of the project described in this report was to conduct a Test and Evaluation (T&E) on a new trouble-shooting concept known as Logic Model (LOGMOD) Diagnostics. The T&E was performed to measure the overall efficiency and effectiveness of LOGMOD as a troubleshooting aid in compare-son to conventional troubleshooting procedures. Specific areas of measurement were:

1. Accuracy of Troubleshooting Aid.
2. Erroneous Part Removals.
3. Troubleshooting Time.

Method

The test approach selected for evaluation of the LOGMOD concept was to simulate the maintenance environment with a test van laboratory and use of the AN/APN-147 doppler radar. A total of 20 problems (4 on-equipment and 16 off-equipment) were built for insertion into the AN/APN-147 doppler equipment. Malfunctions were validated and symptoms catalogued before testing began. Performance tests were then administered to technicians possessing three different levels of experience on the AN/APN-147 doppler radar - no experience, limited experience, and fully experienced. Each experience level consisted of ten test subjects. Ten problems were presented to each subject, five for LOGMOD solution and five for TO solution, a total of 300 problem solving efforts. The test extended over a 90-day period at Norton AFB, California.

CONCLUSIONS AND RECOMMENDATIONS

The analysis of data collected during the T&E supports the following conclusions:

1. LOGMOD is a workable concept and could serve as an efficient and effective troubleshooting aid.

2. Subjects preferred LOGMOD over other troubleshooting aids at the intermediate level of maintenance. Consequently, there is a high probability of user acceptability if the LOGMOD concept is applied to other Air Force systems at this level of maintenance.

3. As shown below, the performance of subjects when using each aid varied with experience levels, maintenance levels, and assembly levels:

   a. For subjects with no experience there was no measurable difference in performance between troubleshooting aids (TOs, FPTAs and LOGMOD).

   b. Subjects with limited experience troubleshot faster at organizational level maintenance when using TOs.

   c. Subjects with limited experience troubleshot faster at the component level of assembly when using LOGMOD.

   d. Subjects with limited experience solved more problems at the intermediate level of assembly when using LOGMOD.

   e. Subjects with limited experience solved more problems at the component level of assembly when using LOGMOD.

   f. Experienced subjects troubleshot faster at both the organizational and intermediate level when using TOs.

   g. Experienced subjects troubleshot faster at the SRU level of assembly when using TOs.

Based on the results of this T&E, the following recommendations are made:

1. The AFLMC should perform a preliminary analysis of the feasibility of conducting a follow-on field test (as specified in Proposal For Test and Evaluation of the Logic Model Diagnostic System Approach To Troubleshooting, 18 March 1977 and LOGMOD Diagnostics Detailed Test Plan, 15 January 1978) to further evaluate LOGMOD capabilities. The field test should be conducted on a system that is (1) a complex system which consumes a large number of man hours in troubleshooting time and which experiences lengthy out-of-commission times and (2) a system for which existing troubleshooting procedures are not effective to a satisfactory degree. Test stations associated with integrated avionics systems, such as those employed in F-l11, F-15 and F-16 aircraft meet the above criteria. However, the scope of the field test should be limited to troubleshooting test stations for a specific weapon system. The preliminary analysis will encompass an economic analysis to insure that savings to be realized outweigh the cost of development.

2. Those Air Force agencies who are responsible for the design, development and acquisition of new systems should consider use of LOGMOD in the development and validation of new troubleshooting procedures. This is perhaps the area where LOGMOD has the greatest potential since it should result in fully validated troubleshooting procedures and could also reduce the voluminous quantities of TOs associated with major weapon systems.

3. AFHRL should become involved in further development and refinement of the LOGMOD concept and determine/evaluate human factor implications.

4. The AFLMC, in conjunction with those agencies responsible for the development of troubleshooting aids, should closely monitor Army and Navy efforts involving LOGMOD to capitalize on the progress and lessons learned by other military services.

5. The AFLMC and those agencies responsible for the development of TOs should also monitor other industry efforts which employ an approach similar to LOGMOD, some of which are under development at this time.

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INTRODUCTION

1. Background. The continuing effort of the Air Force to find better and more efficient ways to maintain its equipment has established the need to evaluate new concepts. Increased weapon system complexity, coupled with reduced manpower and the trend toward shorter formal training, has hastened the requirement to find new and improved ways of maintaining Air Force equipment. Time to troubleshoot, or fault isolate, malfunctions on Air Force equipment constitutes a large portion of maintenance man hour expenditure and is therefore a very lucrative area for significant savings. Improvements in troubleshooting procedures also translate directly into increased readiness of our forces. One new troubleshooting concept known as Logic Model (LOGMOD) Diagnostics, which could offer significant advantages over conventional troubleshooting methods, has been developed. The LOGMOD concept utilizes an automated strategy and a diagnostic test set to isolate equipment malfunctions. The troubleshooting strategy for each system/subsystem is recorded on an individual floppy disc that is used in conjunction with the test set.

2. Test Purpose. Department of Defense Directive 5000.3, January 19, 1973, established the requirement to evaluate new systems before implementation. The overall purpose of the LOGMOD Test and Evaluation (T&E) was to provide an objective assessment of the military utility and operational effectiveness of the LOGMOD concept for troubleshooting Air Force equipment. The results of this T&E will enhance the military's ability to objectively assess LOGMOD's value and help determine application and the need for further evaluations. The specific objective of the test was to gather empirical data for a

comparative analysis of conventional troubleshooting methods and LOGMOD. Test actions focused on identifying, measuring, and recording significant differences in levels of effectiveness between LOGMOD and current troubleshooting methods. Specific areas evaluated were: (1) accuracy of the troubleshooting aid in terms of problems solved-the ratio of the number of problems correctly solved to the number of problems attempted, (2) erroneous part removals-the ratio of the number of incorrect parts used to the number of problems attempted and, (3) troubleshooting time the amount of elapsed time required to successfully solve a problem. Significant improvement in any of these areas could lead to substantial savings and increased readiness. Any troubleshooting approach which requires less technical training and increases the production of first term airmen is very attractive to maintenance managers at all levels. Based on contractor claims and demonstrations, LOGMOD appeared have this potential, hence the need for the test

functional logic model of the system malfunction which can be detected by checking the terminal events of a generated logic model.

Actual operation of the test set is relatively simple (see Appendix A). After applying power and activating the test set, the floppy disc is inserted into the test set and the particular system to be troubleshot is brought online through use of a three digit code. The operator inputs "good" or "bad" responses concerning observed or measured parameters through an abbreviated 16 key alphanumeric keyboard that is attached to the test set. There is no physical connection between the system or equipment under test and the LOGMOD test set. A thin-line alphanumeric plasma display (480 character capability) built into the test set is used to present visual instructions to the operator on precisely what steps to take in order to troubleshoot the system under test. If the specialist follows instructions exactly, and if the strategy. is correct, he cannot fail to find a malfunction within the system.

The test set used in this T&E was manufactured using off-the-shelf, state-of-the-art modular components. Its major components are a case, mini-processor, power supply, electronic boards, plasma display screen, and a disc drive. The test set contour resembles a small portable suitcase and weighs approximately 25 lbs (see Figure 1). Its physical

TEST CONDUCT

1. Approach. Each test subject was briefed on the purpose and extent of the LOGMOD T&E. Each was told that LOGMOD, not the individual, was being evaluated and that the data collected would be used in a comparative analysis to evaluate LOGMOD potential. To ensure that observed differences in performance were caused by the troubleshooting technique and not the specialist's lack of knowledge in using the required test equipment, training programs were available for the test equipment required to maintain the AN/APN-147 doppler radar (see Figure 2). The programs were prepared as individual self-taught packages with the instructions presented in a programmed text format. Subjects received proficiency training on support equipment as determined necessary by the test administrator. Proficiency tests were administered only when the specialist indicated a questionable proficiency. The final phase of training consisted of instructions on the LOGMOD concept and diagnostics test set that included a demonstration of proper hookup and operation, cautions, etc. Each subject had the opportunity to demonstrate proficiency on the LOGMOD test set by performing checkout and trouble-shooting tasks on the test bench mockup.

Prior to the test, each candidate problem was inserted into the mockup to verify and catalog the operational symptoms

associated with the failed LRU, SRU, or component (see Appendix B). Once the known effects of the fault were identified, a systematic evaluation of the accuracy of each troubleshooting aid used in the test was made based on actual troubleshooting performance on the mockup.

The performance test approach was used in the test conduct of LOGMOD. In its broadest connotation, this approach simulates the maintenance environment by having specialists perform maintenance tasks under controlled conditions. For each test the specialist was told to troubleshoot a problem using the appropriate troubleshooting aid. The Test Administrator, in conjunction with the AFLMC representative, monitored the specialist's performance and recorded errors made, parts used, problems encountered, accuracy of the troubleshooting aid, and the time required to complete the task. This technique thus closely simulates the maintenance environment while controlling most of the extraneous factors which affect performance.

Questionnaires were developed to measure the attitude of the test subjects towards each type of troubleshooting aid and were administered after the subject had completed all problems. The questionnaires asked the subjects to rate the troubleshooting aid on factors such as ease of understanding and suitability for different levels of maintenance.

to the component level. Hence, a more representative sample of realistic AN/APN-147 doppler radar malfunctions was included in the test because detailed information, not available from formal Air Force information systems, was obtained on the specific parts or components which contribute most to the maintenance problems of the AN/APN-147 system. The contractor in development of the troubleshooting strategles, had no knowledge of what the problems would be. Care was exercised to Insure that this confidentiality- was -maintained

5. Test Facilities/Environment. The LOGMOD T&E required dedicated access to prime equipment for extended periods of time. It was also known that it would not be possible to obtain sufficient access to test benches at Norton AFB without causing an unacceptable degree of interference with the 63 MAW's mission. To ensure adequate access to dedicated equipment, the AFLMC's van (see Figure 3) served as the experimental setting for the controlled T&E of the LOGMOD. The AFLMC's 40 foot van was equipped with a bench mockup (see Figure 4) of the AN/APN-147 doppler radar and a compartment which closely simulates the cockpit and avionics equipment bays of the C-141 aircraft. All AN/APN-147 components were "live" and functional to the same extent as that equipment in an actual aircraft. All other components on the instrument panels were represented by photographs. The van provided the

c. Time to troubleshoot.

c. Erroneous part removals.

d. Attitudes of the subjects.

4. Proportional Analysis Methodology. Descriptive statistics (Arithmetic means) were used in comparative analysis for determining the relative effectiveness of three types of troubleshooting aids (TOs, FPTAs, and LOGMOD) based on four parameters - accuracy, problems solved, erroneous part removals, and troubleshooting times. Each parameter was first categorized by maintenance level and then comparisons were made using experience level/type troubleshooting aid combinations for each maintenance level. Off-equipment parameters were further categorized by levels of assembly and comparisons were made using experience level/type trouble-shooting aid combinations for each level of assembly.

a. Accuracy Analysis. The criterion used to determine the accuracy of a troubleshooting aid was whether or not the aid could lead a subject to the malfunction, given that he had used it correctly. In instances where it appeared that the aid could not isolate a malfunction, the test administrator verified this condition by attempting to fault isolate the malfunction himself, using the same troubleshooting aid.

b. Problems Solved. Given that a troubleshooting aid could isolate the malfunction, the criterion used to determine the proportion of problems solved was whether or not the aid could fault isolate within a specified time. The established standards specified that the maximum time allowed for fault isolation was 75 minutes for a single fault and 90 minutes for multiple faults. If the maximum time was exceeded, the problem was tabulated as not solved. During level of assembly analysis there was one exception to this rule. Although the overall time was exceeded, the intermediate times were used in the analysis.

c. Erroneous Part Removals. Given that the troubleshooting aid could isolate the malfunction, the criterion used to determine if it was an erroneous removal was whether or not the fault was corrected when the part was replaced. However, if the troubleshooting specified Substitution of a part to determine if it was defective, (this is the strategy used in FPTAs) erroneous part removal was not counted even if- it did not correct the malfunction.

d. Troubleshooting Time. If the troubleshooting aid did solve the problem within the established time constraints, the times were used in the comparative analysis. Otherwise, they were discarded.

5. Statistical Analysis Methodology. The experimental design for this test was selected to resemble the design used by the AFHRL in conducting a previous similar study, as documented in Patter and Thomas, Evaluation of Three Types of Technical Data for Troubleshooting: Results and Project Summary, unpublished AFHRL report. The statistical methods originally planned for this test were also patterned after the AFHRL study and were based on a three factor repeated measures Analysis of Variance (ANOVA) design. However, three conditions developed which precluded adherence to this original plan and necessitated the development of alternative methodologies.

a. The test subjects without any prior experience with the AN/APN-147 radar were instructed to use FPTAs while troubleshooting the off equipment problems. The objectives of the test were thereby broadened to include a comparison of the effectiveness of the LOGMOD device to the effectiveness of the FPTAs, in addition to the LOGMOD/TO comparison. Additionally, of the twenty problems comprising the test problem set, one problem could not be solved using the LOGMOD device and procedures; two problems could not be solved using the standard TOs and four problems could not be solved using the FPTAs. There was not sufficient time to construct problems to replace this set of problems, and since inclusion of all

twenty problems might well have introduced an unacceptable bias into the test in favor of the LOGMOD device, the errant problems were excluded from the analysis. The exclusion of these problems, and the introduction of the

TEST RESULTS

1. Findings. The findings are presented using two different techniques. The proportional analysis presentation is intended to portray the results in a clear unencumbered form. The statistical analysis presentation treats the same results in a different form using detailed support to allow independent assessment of the material presented.

2. Proportional Analysis.

a. On-and Off-Equipment Comparison.

(1) Accuracy of Troubleshooting Aids. The adequacy of each troubleshooting aid to fault isolate the test problems is depicted in Figure 8. Overall results show that, LOGMOD could solve greater percentage of problems (95%) than either TOs (90%) or FPTAs (75%). At the organizational level LOGMOD could solve 100% of the problem, TOs 75%, and FPTAs were not used. At the intermediate level both TOs and LOGMOD could solve 93.75% of the problems and FPTA could solve 75%. Based on these results, whenever comparative analysis was performed between TOs and LOGMOD, the data for problems 2 and 11 were discarded for both troubleshooting aids. When the comparison was between FPTAs and LOGMOD, the data for problems 5, 9, 11, 12, and 18 were discarded for both aids.

Objective: To determine if there was a significant difference between the number of problems solved using LOGMOD and the number of problems solved using TOs.

Subject and Problem Category: This example analysis was restricted to the Category 2 subjects, solving off-equipment problems.

Of the original 16 off-equipment problems, one problem was ignored in the analysis since it could not be solved by the LOGMOD device or by the TOs. The test measure was computed for the remaining fifteen problems with the following results:

TABLE 1 EXAMPLE

ANALYSIS

Problem Set Number	% Subjects Successful Using TOs	% Subjects Successful Using LOGMOD
1	100	100
2	100	100
3	50	100
4	33	50
5	100	100
6	66	100
7	66	100
8	100	100
9	33	100
10	50	100
11	100	100
12	100	100
13	66	50
14	100	100
15	66	50

measure, this measure was evaluated using the Wilcoxon Signed Rank Test, with the following null and alternative hypothesis:

Null Hypothesis: No difference in the responses for each troubleshooting aid.

Alternative Hypothesis: The erroneous removal percentage using LOGMOD is less than the percentage using the alternative troubleshooting aid.

The analysis results for the erroneous part removals test measure are depicted in Table 4 in the same manner as Table 2. As before, the Cat 1 table entries are for a test of the difference between FPTAs and LOGMOD, while the Cat 2 and Cat 3 table entries are for a test of the difference between TOs and LOGMOD. Again it was not necessary to test for any differences for the on-equipment problems since a11 of the test measures were the same except for one case which could not result in statistical significance.

TABLE 4

Erroneous Part Removals Analysis Results

	Cat 1	Cat 2	Cat 3
Off-Equipment	.289	.404	.156
LRU to SRU	---	---	.438
LRU/SRU to Component	.125	.273	.125

4. Additional Findings: At times during the LOGMOD test the AN/APN 147 equipment malfunctioned. In most cases the test administrator was able to quickly determine the cause of the malfunction through experience and use of conventional TOs. However, in some cases when he was not able to determine the cause of the problem, he used LOGOMOD to successfully isolate the malfunction.

Another finding of significance, which was not part of the evaluation, was that changes can be made quickly and easily to the LOGMOD troubleshooting strategy. During the initial evaluation effort, the contractor made frequent and sometimes extensive changes to the strategy, most of which were completed in-a-few hours. This is a particularly desirable feature in view of the frequency with which TOs must be revised and republished.

5. Subject Attitude: Summary information on the opinion expressed by the subjects towards the use of TOs, FPTAs and LOGMOD is contained in Appendix C. Responses to opinion questions concerning the use of the troubleshooting aids for various levels of assembly troubleshooting were fitted along a Likert-type scale. Possible range of scores was from 0 to 100. The mean score values expressed by the subjects about the usefulness of TOs, FPTAs and LOGMOD are reflected in Figure 15.

How do you feel about the (LOGMOD, TOs, FPTAs) as an aid in troubleshooting the maintenance problems you have just had at the following levels of maintenance?

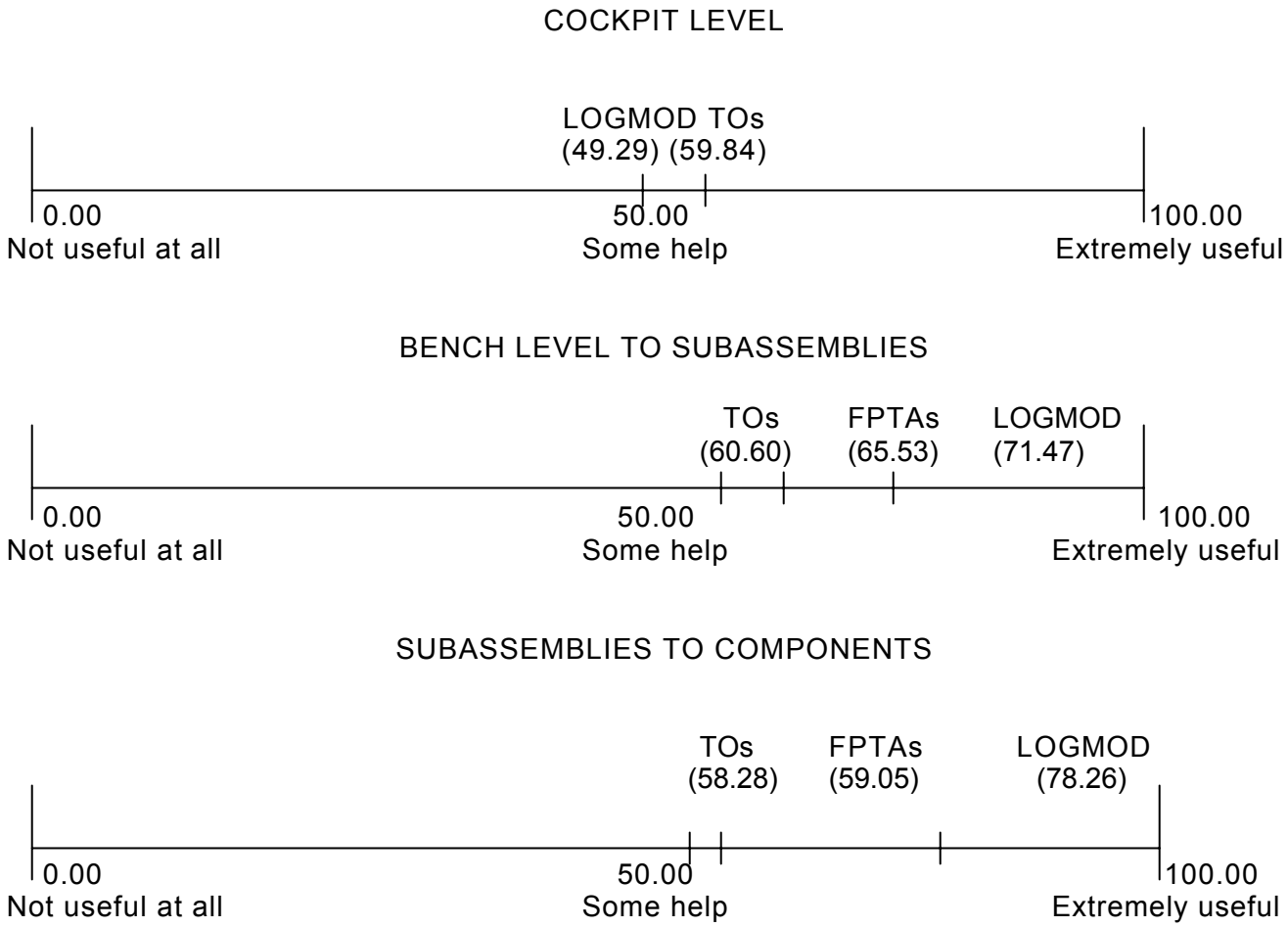

FIGURE 15. OPINION RESULTS OF SUBJECTS TO QUESTIONS ABOUT THE USEFULNESS OF THE TYPES OF TROUBLESHOOTING AIDS

Clearly, the subjects favored LOGMOD over FPTAs and TOs for Intermediate level type tasks and TOs over LOGMOD for organizational maintenance tasks. In addition to the subject's opinion about the use of TOs, FPTAs and LOGMOD, each subject was asked to give his opinion with respect to the ease of understanding of the troubleshooting aids. Again the possible range of scores was from 0 to 100. The mean score values expressed by the subjects about the understandability of each troubleshooting aid is depicted in Figure 16. Clearly, the subjects believe they understand LOGMOD better than FPTAs or TOs

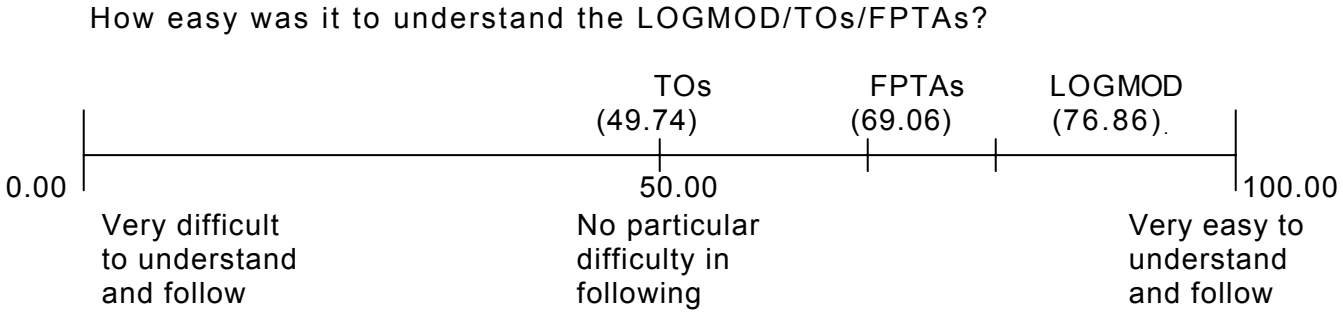

FIGURE 16. OPINION: RESULTS OF SUBJECTS TO QUESTIONS ABOUT THE UNDERSTANDABILITY OF BOTH TYPES OF TROUBLESHOOTING AID

DISCUSSION

1. Introduction. The results of the test demonstrate that, with some modification to the LOGMOD troubleshooting strategy and with selective application to troublesome and complicated systems, the LOGMOD concept is suitable for Air Force application. Although test results in many areas were somewhat inconclusive, (LOGMOD performed better in some areas while TOs or FPTAs performed better in other areas), LOGMOD potential has been validated. To put the project in perspective, it should be recognized that those involved in project development of LOGMOD were inexperienced and had to go through a learning process. From the contractor standpoint, this was the first attempt to develop a strategy for actual Air Force use. He had to become familiar with Air Force repair levels, field terminology, and the Air Force way of doing business. Because of this limitation the project took longer to accomplish than originally planned and, more significantly, the strategies developed did not approach the optimum level for troubleshooting the system. The experience gained by the contractor and the Air Force on this project should be invaluable on future developments of LOGMOD or similar concepts.

A summary of those findings that were statistically significant is depicted in Table 12.

CONCLUSIONS AND RECOMMENDATIONS

The analysis of data collected during the T&E supports the following conclusions:

1. LOGMOD is a workable concept and could serve as an efficient and effective troubleshooting aid.

2. Subjects preferred LOGMOD over other troubleshooting aids at the intermediate level of maintenance. Consequently, there is a high probability of user acceptability if the LOGMOD concept is applied to other Air Force systems at this level of maintenance.

3. As shown below, the performance of subjects when using each aid varied with experience levels, maintenance levels, and assembly levels:

   a. For subjects with no experience there was no measurable difference in performance between troubleshooting aids (TOs, FPTAs and LOGMOD).

   b. Subjects with limited experience troubleshoot faster at organizational level maintenance when using TOs.

   c. Subjects with limited experience troubleshot faster at the component level of assembly when using LOGMOD.

   d. Subjects with limited experience solved more problems at the intermediate level with LOGMOD.

   e. Subjects with limited experience solved more problems at the component level of assembly when using LOGMOD.

   f. Experienced subjects troubleshot faster at both the organizational and intermediate level when using TOs.

   g. Experienced subjects troubleshot faster at the SRU level of assembly when using TOs.

Based on the results of this T&E, the following recommendations are made:

1. The AFLMC should perform a preliminary analysis of the feasibility of conducting a follow-on field test (as specified in Proposal For Test and Evaluation of the Logic Model Diagnostic System Approach to Troubleshooting, 18 March 1977 and LOGMOD Diagnostic Detailed Test Plan, 15 January 1978) to further evaluate LOGMOD capabilities. The field test should be conducted on a system that is (1) a complex system which consumes a large number of man hours in troubleshooting time and which experiences lengthy out-of-commission times and (2) a system for which existing troubleshooting procedures are not effective to a satisfactory degree. Test stations associated with integrated avionics systems, such as those employed in F-111, F-15 and F-16 aircraft meet the above mentioned criteria. However, the scope of the field test should be limited to troubleshooting test stations for a specific weapon system. The preliminary analysis will encompass on economic analysis to insure that savings to be realized outweigh the cost of development.

2. Those Air Force agencies who are responsible for the design, development and acquisition of new systems should consider use of LOGMOD in the development and validation of new troubleshooting procedures. This is perhaps the area where LOGMOD has the greatest potential since it would result in fully validated troubleshooting procedures and could also reduce the voluminous quantities of TOs associated with major weapon systems.

3. AFHRL should become involved in further development and refinement of the LOGMOD concept and determine/evaluate human factor implications.

4. The AFLMC, in conjunction with those agencies responsible for the development of troubleshooting aids, should closely monitor Army and Navy

efforts involving LOGMOD to capitalize on the progress and lessons learned by other military services.

5. The AFLMC and those agencies responsible for the development of TOs should also monitor other industry efforts which employ an approach similar to LOGMOD, some of which are under development at this time.

TABLE C-3. RESPONSE: OF TEST SUBJECTS TO THE QUESTION: WHICH TROUBLESHOOTING AID WAS EASIER TO FOLLOW?

	TYPE TROUBLESHOOTING AID		
EXPERIENCE LEVEL	FPTAs	TOs	LOGMOD
CAT 1	6	---	4
CAT 2	---	0	10
CAT 3	---	2	8
TOTALS	6	2	22

NOTE: Only Cat 1 subjects used FPTAs

CAT 1 - No Experience
CAT 2 - Limited Experience CAT 3 - Experienced

Comments:

TOs are easier to follow because:

- I'm more familiar with TOs.
- . It is easier to go back to a previous step than it is using L0GMOD.

FPTAs are easier follow because:

- FPTAs have visual aids and illustrations.
- FPTAs show pictures of test points and switches.

LOGMOD is easier to follow because:

- LOGMOD gets to the malfunction faster.
- LOGMOD is a thinking TO.
- It is simple, easy to read and understand, hence, it is easier to follow.
- It is more direct and no skipping around is involved.
- There is less chance of error.
- This is not a fair comparison because the TO is exceptional poor.

TABLE C-4. RESPONSE OF TEST SUBJECTS TO THE QUESTION: WHICH TR0UBLESHOOTING AID WAS THE MORE EFFECTIVE?

	TROUBLESHOOTING AIDS			
EXPERIENCE LEVEL	FPTAs	TOs	LOGMOD	BOTH
CAT 1	2	---	4	4
CAT 2	---	1	5	4
CAT 3	---	3	5	2
TOTALS 3	2	4	14	10

NOTE:

CAT 1 - No Experience
CAT 2 - Limited Experience
CAT 3 Experienced

Comments:

TOs are more effective because:

- It is easier to locate malfunctions.
- Use of schematics provide faster fault isolation.

LOGMOD is more effective because:

- LOGMOD took the guessing out of finding a defective component.
- LOGMOD converts TO data into a readable and useful format.
- LOGMOD solved more problems.
- LOGMOD is clearer, simple, and faster.
- LOGMOD went right to the problem.
- With LOGMOD there is less chance of error.

Both troubleshooting aids are effective because:

- Both found the malfunctions.
- TOs were more effective for organizational level tasks while LOGMOD was more effective for inter-mediate level tasks.
- No preference.

TABLE C-5. RESPONSE OF TEST SUBJECTS TO THE QUESTIONS WOULD YOU LIKE TO SEE LOGMOD USED ON OTHER AIRCRAFT SYSTEMS? AT WHAT LEVEL OF MAINTENANCE?

EXPERIENCE LEVEL	USE ON AIRCRAFT	OTHER SYSTEMS	MAINTENANCE LEVEL	
	NO	YES	ORG	INT
CAT 1	3	7	6	7
CAT 2	0	10	4	10
CAT 3	1	9	4	9
TOTALS	4	26	14	26

NOTE:

CAT 1 - No Experience
CAT 2 - Limited Experience
CAT 3 - Experienced