A PLAN FOR THE EVALUATION OF THE F-16 SIMULATED AIRCRAFT MAINTENANCE TRAINERS (SAMTs)

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ABSTRACT

A research plan was developed to evaluate the cost and training effectiveness of the F-16 SAMTs. Historically, such evaluations have been conducted by comparing the effectiveness of the simulator against that of an actual equipment trainer (AET). However, readily comparative training devices and approaches do not exist in the case of the F-16. To evaluate the training effectiveness of the SAMTs, a criterion referenced approach was selected. Students will be assessed on their ability to perform maintenance tasks, taught using the SAMTs, on actual F-16 aircraft. End-of-course measures and follow-up retention testing will be conducted. Engine, pneudraulic, electrical, and flight control system tasks will be evaluated. Task selection criteria include difficulty, criticality, and frequency of performance. Specific training capabilities of the SAMTs to be assessed include two instructional features: the malfunction insertion capability and automatic student monitoring. A comparison will be made between the performance of students trained with the malfunction insertion feature operational versus without this instructional capability. The use of the student monitoring capability will be assessed through interviews with the course instructors. A comparative approach was adopted for assessing the cost effectiveness of the SAMTs. The cost of the hypothetical AET delivery system with the same set of learning objectives as the courses the SAMTs are utilized in will be computed and compared to the SAMT delivery system. Major categories in the cost model include facilities, instructional equipment, instructional materials, personnel, and supplies.

INTRODUCTION

Traditionally, maintenance skills such as calibration, inspection, troubleshooting, and repair have been acquired using Actual Equipment Trainers (AET). However, the use of actual equipment in the training situation has not been without practical problems. These problems are well documented in the literature. Some of the problems include:

- Extremely Low Reliability. Actual equipment is sensitive and delicate and in the training situation the actual equipment can be subjected to student-induced damage. Low reliability results in low availability for training purposes.

- Low Maintainability. Traditionally, spare parts for training has had a low priority. This decreases the availability of the equipment for hands-on practice.

- Limitations. Frequently the components or units to be tested cannot be "failed" in the ways necessary to provide complete and meaningful troubleshooting practice. In addition, emergency conditions often cannot be fully practiced.

These problems, coupled with the generally high initial cost of AET, encouraged the search for a viable alternative.

Growing consideration has been given to the concept of simulation. Maintenance training simulators are expected to:

- Reduce Cost. The initial cost and the operational and maintenance costs of simulators are expected to be lower. Furthermore, a lower downtime rate means increased availability for training.

- Improve Training. Simulators should *provide improved training not only* through higher availability rates, but through such built-in capabilities as:

  - Automatic student monitoring.

  - Increased availability of more varied student exercises (more malfunction identification and/or correction and emergency situation problems).

  - Immediate feedback to reinforce correct responses.

  - Programmed remedial instruction with in-depth explanation of course content.

  - A trainer with built-in capabilities can function with less instructor dependency; i.e., students can engage in practice without the need for an instructor, thereby decreasing instructor demand.

With these expectations in mind, the USAF acquired a set of F-16 Simulated Aircraft Maintenance Trainers (SAMTs). The SAMTs are the first in an anticipated series of maintenance trainers for major weapons systems. As such, the SAMTs represent an opportunity to determine if the expectations of reduced cost and improved training capability have been realized. Plans for assessing the training and cost effectiveness of these simulators are described in the following sections.

APPROACH

Training effectiveness and cost effectiveness evaluations of simulators are not a new idea. Historically such evaluations are conducted by comparing the cost and training effectiveness of the simulator against the cost and training effectiveness of actual equipment trainers (AETs); i.e., in the past, readily comparative devices and training approaches have existed. This is not the case with the selected F-16 SAMTs; no F-16 AETs exist nor are there any plans to acquire AETs. In addition, because of the newness of the curriculum, there is no baseline data on past student performance and proficiency. Thus, the possibility of comparing the performance of students trained on the selected SAMTs with the performance of students who have been trained using an alternative training program or approach does not exist.

The approach used to evaluate the SAMTs, as well as the results of the evaluation, will influence the acquisition, design, utilization, *and evaluation of future maintenance training* simulators. The problem is to develop a practical cost and training effectiveness evaluation plan which generates accurate and useful data, given that there is no easily identifiable comparative training approach. Separate plans were devised to evaluate training and cost effectiveness.

Cost Effectiveness

The cost model developed for the current evaluation is based on a review of the most relevant information from Air Force directives and regulations and recent economic analysis publications.

Basically, a comparative approach was adopted for assessing the cost effectiveness of the SAMTs. The cost model will be used to compute simulator costs and to estimate the costs which would have been incurred with the purchase of (hypothetical) actual F-16 hardware equipment trainers. These costs will then be compared. The concern in the cost effectiveness evaluation is with comparing the costs of the two types of instructional delivery systems. The media used in each type of delivery system is only part of the cost of the system. That is, the SAMT devices and hypothetical AETs represent only a portion of the cost required to conduct the courses which use the two types of media. For example, the selection of media may influence personnel costs, facility costs, etc. Thus in conducting the cost effectiveness evaluation, consideration must be given to the total delivery system and not just to the type of instructional equipment used.

Assumptions

There will be a hypothetical AET course for each SAMT delivery system. These corresponding AET delivery systems will be designed to have have the same set of learning objectives as the corresponding SAMT delivery systems. It will be assumed that both types of delivery systems are equally training effective, although it is possible for the courses to be different with respect to the student flow, number of instructors required, facility size, instructional material, and supplies. This approach has several advantages:

- Any other assumptions of AET training effectiveness would have to be based on subjective judgment.
- This approach allows the two competing delivery systems to be compared purely on costs.
- The assumption of equal training effectiveness makes only two results possible:
  - Equal benefits and equal costs.
  - Equal benefits and unequal costs.
- There is some evidence in the literature that support the assumption of equal training effectiveness between the two delivery systems.

Another assumption is that the economic life of the SAMTs is identical to their physical life (15 years). Additionally, the economic life of the AETs will also be assumed to be 15 years.

Finally, it is assumed that the SAMTs and AETs are fixed equipment, and that the variable equipment required by each delivery system are identical.

Cost Categories and Features

The cost model developed for use in the F-16 SAMT evaluation effort has the following major cost categories:

- Facility costs.
- Instructional equipment costs.
- Instructional materials costs.
- Personnel costs (cost of salaries and benefits to instructors and students).
- Supply costs.
- Miscellaneous costs.

Each of the major cost factors or categories is subdivided into associated costs. These subfactors define the costs that compose the major cost factor. Subfactors may reflect cost areas such as acquisition, operation, and maintenance. These subfactors are further divided corresponding to the cost area (for example, equipment acquisition costs can be further separated into procurement, shipping, and installation costs).

Although the cost model was compiled specifically for this project, it is general in nature and can be applied to the costing of other types of delivery systems. The cost model has the following features:

- It considers research and development costs as sunk costs.
- It uses the present value cost concept to account for differential cash flow patterns between the competing delivery system. The present value cost method is used to account for possible differences in cash flow for each year of the comparison period for each delivery system being compared.
- It separates implementation costs from the costs incurred in subsequent years.
- It divides the instructional equipment cost category into types of equipment: Fixed Equipment and Variable Equipment.
- It is comprehensive in its list of subfactor costs; i.e., it includes all relevant cost categories and subcategories for training systems.
- It considers the costs associated with updating:
  - The instructional equipment (SAMTs and AET).
  - The instructional features software/courseware.
  - All types of instructional materials.

- It allows for removing from the present value cost, the remaining value of the following at the end of the comparison period:

  - Facilities.
  - Instructional Materials.
  - Instructional Equipment.

- It separates the utility costs required to operate the facility from the utility costs required to operate the fixed equipment (simulator and AET).

Comparing Costs. The present value cost less the remaining value of instruction materials, equipment and facilities will be compared. In addition to comparing the total costs of each delivery system, the following analyses will be made:

- A comparison of the implementation costs of both types of delivery systems. It is expected that one type of delivery system will require more front-end money than the other.

- The costs of the SAMT delivery systems will be compared. It will be of interest to note which SAMT configurations have the highest and lowest costs.

- The major contributing costs within each delivery system will be examined. Are these major contributing costs the same as those for the SAMT delivery system?

- For each corresponding delivery system, accumulative costs per student will be graphed. If the two types of corresponding delivery systems are different (by 10 percent), then a break-even point in student flow will be calculated. This will allow managers to "see" how many students would be trained by the lower cost delivery system for the same cost as the highest cost delivery system.

- For each corresponding delivery system, accumulative costs per operating hour will be graphed. If the two types of corresponding delivery systems are different (by 10 percent), then a break-even point in operating hours will be calculated.

- Within the SAMT delivery system, the costs of the instructional features will be compared.

It is anticipated that the above comparisons will assist the Air Force in determining the cost/benefit derived from both AET and SAMT type delivery systems. Furthermore, it will provide some insight into the cost of the instructional features under study.

Training Effectiveness

A criterion referenced evaluation will be conducted. Basically, this technique consists of evaluating students on their ability to perform the tasks (objectives) presented in the course, after they have been exposed to the training. If, after training, the trainees can perform what the course was designed to impart, then the training can be judged successful or effective. This training effectiveness study is designed to determine if the graduates of F-16 maintenance training programs (which employ SAMTs) can attain criterion on the learning objectives specified in the course documents.

Rationale for Selection of Approach. There are three strong reasons for selecting a criterion referenced assessment approach. First, the absence of F-16 hardware trainers, with the exception of the F-100 engine AET utilized in F-15 maintenance training (the F-15 and F-16 engines are highly similar), prohibits the adoption of a comparative approach in which the effectivenss of a simulator can be gauged against the effectiveness of an AET.

Although no AET is available, the F-16 maintenance courses were designed to be taught with either the SAMTs or on actual aircraft. This would provide a reasonable basis for a comparative study. The effectiveness of the SAMTs and the effectiveness of the actual aircraft could be assessed and these alternative training approaches compared with a high degree of confidence. In fact, the design of such a comparative study would maximize experimental control (i.e., many of the sources of extraneous variance in the dependent measures could be easily controlled). This degree of control would increase the likelihood that any observed difference in student performance could be attributed solely to the SAMTs, since both courses would be identical except for the use of the aircraft. However, this approach raises the following issues:

- It is, perhaps, unreasonable to expect the Air Force to teach five courses using only the aircraft. The logistics problems (for example, dedicating aircraft purely for training) could be overcome, but the problems of guaranteeing that the same instructor teach both groups, that the courses remain identical to the SAMT courses (except for the use of the aircraft), and other such similar problems may be viewed by the FTD as an unacceptable and costly burden.

- It is highly unlikely that the courses (using just the aircraft) have been taught before. This means that any comparative study would be "loaded" in favor of the SAMTs since part of the variance in the comparative dependent measures would be the "newness" of using the aircraft in the courses (particularly when the instructor would be accustomed to using the SAMTs).

Therefore, a second major reason for selecting a criterion referenced approach is that it requires less manipulation of the existing training environment, as opposed to the demands of conducting a comparative study.

The third reason for selecting the criterion referened approach is to best meet the project objective for development of a general assessment model. While the Air Force will undoubtedly continue to purchase some AET, it is unlikely that there will be much opportunity for comparative studies in the future.

Because of these reasons, a criterion referenced approach was selected. This is not to imply, however, that a criterion referenced approach is easier to conduct or without research design problems.

Disadvantages of Criterion Referenced Approach. In a criterion referenced approach, isolating the contribution due to the SAMTs is much more difficult than in a comparative approach. The SAMTs are not used in isolation. The training objectives are achieved in a variety of ways, and it is important that the evaluation methodology accurately separate the contribution of the SAMTs in achieving the objectives from the contribution made by the other course media and methods (videotapes, slides, aircraft, and OJT experiences). A comparative study would be much easier to conduct from this perspective than a criterion referenced assessment.

A second difficulty is that the criterion referenced approach requires clearly stated course objectives. The learning objectives appearing in the F-16 course control documents (CCDs) are terminal objectives. For the most part they are skill or performance-oriented; critical enabling objectives (locating or naming parts) are not identified. Also, some of the objectives require amplification or clarification by instructors. Finally, some of the terminal objectives listed in the CCDs may not match what is expected on the job. The evaluation methodology must validate the stated course objectives and proficiency levels, and verify their consistency with actual job requirements and expectations of field supervisors. Validation is needed since it is possible that the tasks are not longer performed in the same manner.

One final drawback of the criterion referenced approach is that it does not result in direct comparative information. That is, it will not be possible to state that the SAMT training program is better or worse than some other training approach, only whether or not the SAMTs adequately train personnel to meet the stated course objectives.

Explanation of Design. In a criterion referenced approach, the main concern is whether or not the students can perform as expected. (Did the students reach the stated course objectives?) In the present case this question is moderated in the following way: Can students perform as expected, and how much of their performance is due to the SAMTS? The answer to this question can be found by using the following basic research design:

$$X \quad [O_{w1}, O_{w2}, \ldots, O_{wn}] \quad O_1$$

where X denotes the course, O_{wi} within-course measures (to isolate the effects of other media), and O_1 denotes the dependent performance measure taken immediately following the course. (Since the use of various media within the course is fairly well blocked--generally only one type of media is used within an instructional segment and the courses typically call for a written within-course exam at the end of each block--it should be possible to segregate the effects of these other media through the use of within-course measures, administered at the end of each instructional block as needed.)

In order to assess how well students retain their training, a follow-up measure is taken several weeks following the end of the course. The design then becomes:

$$X \quad [O_{w1}, O_{w2}, \ldots, O_{wn}] \quad O_1 \quad O_2$$

Some degree of comparison is possible in the research study. The evaluation of the malfunction insertion capability will involve having the instructors teach some classes with the instructional feature operational and other classes with the capability turned off. The performance of these two groups of students will then be compared. The two mode design thereby assesses the malfunction insertion capability by measuring training effectiveness of the SAMT (student performance) with the feature operational, and comparing this data with training effectiveness of the SAMTs when the feature is turned off.

The automatic student monitoring feature will be assessed in a different manner. Instructors will be interviewed and asked to describe how they used the monitoring feature. This information can then be used to structure or recommend more in-depth study.

Sample

SAMTs. Not all of the F-16 SAMTs are targeted for evaluation. Trainers for the pneudraulic, electrical, flight control, and engine systems were selected. These SAMTs were chosen because they represent the range of maintenance task complexity and difficulty. Also, the selected SAMTs vary in configuration.

Each SAMT consists of at least one simulator panel set (SPS) and a master simulator control console (MSCC). The engine operation procedures SAMT is configured as a simulated cockpit.

The other SPSs are vertical flat display panels which pictorially illustrate the location and relationships of the components of each of the major aircraft systems. Both cockpit and vertical flat panel trainers are included in the study.

Also, positioned on each of the panels are simulated test equipment which provide the student with the facilities to troubleshoot simulated malfunctions to a particular location, and to simulate removal and replacement of defective components. Test set connection/disconnection, remove/replace operations and visual inspection steps consist of pushing annotated buttons.

The MSCCs are composed of a Honeywell series 6/36 mini-computer with keyboard/CRT (cathode ray tube) input-output mode, random access 35mm slide projector and hardcopy line printer. The MSCC contains the hardware and software interfaces which operate the SPSs and provides the instructional software.

The simulators are designed to be used by two students at a time. The instructor initializes the system via the MSCC, selects the lesson to be presented, and turns the simulator over to the student. The student then attempts to operate, calibrate, or troubleshoot the system with the aid of the applicable technical orders and job guides. The simulator monitors the progress of the student, administers feedback via CRT or slides, and records time and error as the student works through the problem. For the most part, the simulator responds to the student's inputs as would the actual equipment. Obviously, there are limits to the simulator responses, and these are generally constrained by the SAMT hardware.

Trainees. Maintenance trainees come from a variety of backgrounds. For the purposes of this study, only 3-levels (trainees just coming out of technical school), and 5-levels are being evaluated. Foreign students, civilians, and higher level military personnel (7- and 9-levels) are excluded.

Tasks. Training effectiveness will be evaluated primarily through assessing student performance. Performance testing will consist of observing students during fault isolation procedures, ops checks, and locate/identify drills on the aircraft (in some cases, the tasks have to be performed on the SAMT instead of the aircraft). Task protocols were developed from T.O.s and translated into checklists to be used as a basis for scoring students. These observational checklists detail, in a step-by-step fashion, the actions the trainee should execute.

For each course, a set of tasks were selected to use as a basis for evaluating student performance. Basically, two types of tasks were chosen for each course: operational checkouts (procedural tasks) and fault isolation tasks (problem-solving tasks which involve a knowledge of system logic to find the cause of an aircraft malfunction). Selection criteria included the following:

- Representative of system maintenance skills and knowledge.
- Task difficulty and length.
- Frequency of task performance on flight line.
- Support equipment, materials, and personnel requirements.
- Feasibility of installing nonfunctioning components in the aircraft to present a malfunction situation.
- Potential danger to personnel.
- Potential damage to aircraft.

Data Collection. Other data to be collected include:

- Pretraining information (student record files and profile questionnaire).
- Within-course skill/knowledge tests (currently administered by instructors at the end of instructional blocks).
- Standard end-of-course multiple choice exams.
- Instructor attitudes (questionnaire).*
- OJT log (trainee task experience record).
- OJT supervisor evaluation of student performance (questionnaire).
- Student attitudes (end-of-course and post-training questionnaires).

Method. In order to understand the sequence of data collection and testing, it is necessary to review/describe how maintenance training is conducted. First, students attend training at a technical school. Following this basic systems education, trainees are assigned to an Air Force Base and receive their in-depth aircraft system training. This is the SAMT portion of their education. SAMT course length ranges from 3 to 26 days. After successful completion of the SAMT course, trainees go to on-the-job training (OJT).

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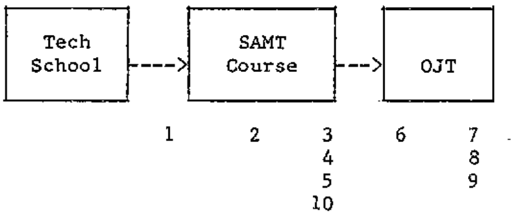
* The Instructor Attitude Questionnaire will be the vehicle for gathering information on the automatic student monitoring feature. Specifically, they will be asked to rate the utility of this feature, list strengths and weaknesses, estimate the amount of use of the feature, describe how and when they used the feature in the classroom.

The study assesses performance (and student attitudes) at the end of the SAMT course, and again approximately six weeks later. In addition to the student performance and attitude data (end-of-course and retention) measures, within-course testing (standard exams) are given. These measures should help in isolating the effects of the SAMTs from other course media. (Indeed, besides slides and overheads, some courses involve hands-on aircraft training along with SAMT exercises.) The data collection timeline is presented in Figure 1.



1. Student File Data/Profile Questionnaire
2. Within-Course Exams (written)
3. End-of-Course Exams (written)
4. Student Attitude Questionnaire (1)
5. End-of-Course Performance Measure
6. OJT Log
7. Student Attitude Questionnaire (2)
8. Retention Performance Measure
9. Supervisor Rating
10. Instructor Attitude Questionnaire

Figure 1
Sequence of Training
and Experimental Measures

Evaluation of Training Effectiveness. Of primary concern in the current study is the proportion of students trained using the SAMT who pass/fail the stated course objectives which are targeted for evaluation or assessment. More specifically, the following research hypotheses will be statistically tested:

- At least 70 percent of the students will reach the stated proficiency level on the objectives targeted for evaluation at the end of SAMT training.
- At least 70 percent of the students will reach the stated proficiency level on the objectives targeted for evaluation at the time of retention testing.
- At the end of the course, it is hypothesized that the proportion of students passing the objectives to the malfunction turned-off mode will be significantly lower than the proportion of students exposed to the malfunction turned-on mode.
- Six weeks after the SAMT training, there will be no significant difference between the proportion of students passing the stated objectives (at the stated proficiency levels) in either of the three experimental modes (malfunction ON and malfunction OFF). This hypothesis contends that any differences between the three modes at the end of training will be "washed out" by the time the retention measure is taken; i.e., the instructional feature effect will disappear.
- The proportion of students passing the stated objectives will be significantly greater after OJT than immediately after the SAMT course, provided that the OJT experience supports the training. The converse is hpothesized for those students who have OJT experience which does not support the training. The OJT log will be used to determine whether or not the OJT experience supports the training. The following rule of thumb will be used. If a student performed the task targeted for evaluation three times or less during the OJT experience, then the OJT experience will be classified as not supporting the training.
- The level of confidence reported on the student attitude questionnaire will increase between the end of training and the time of the retention measure, provided that the OJT experience supports the SAMT training. The converse is hypothesized for those students where the OJT experience does not support the training.
- Positive attitude toward the SAMTs will increase from the end of training to the time of the retention measure, provided that the OJT experience supports the training. The converse is hypothesized in those cases where the OJT does not support the training. Attitudes will be determined from the student attitude questionnaire. Positive attitude will be determined using the following rule of thumb. A perfect positive attitudes score is one in which the student indicated the maximum value for each item on the questionnaire. A perfect negative attitude score is one in which the student indicates the minimum value for each item on the questionnaire.

In addition to the above formal hypotheses, the following descriptive indices will be calculated in order to provide a more meaningful basis for interpreting the data:

- The backgrounds of students not reaching criterion at the end of training will be summarized. This summary might help to determine which type or kind of students benefit least from the SAMT type of training program.

- The average knowledge test score (in-class measure) of those students reaching and not reaching criterion will be calculated. A direct statistical comparison will not be performed, since such information adds little to the problem at hand. However, it should be realized that knowledge measures may help to interpret the performance data.

- The supervisor ratings of those students failing both the end-of-course measure and the retention measure will be calculated. These indices will be reported along with the degree to which the OJT experience supported the training in order to put the supervisory ratings in the proper perspective.

- The correlation between the supervisor ratings and both the end-of-course performance measures and the retention measures will be calculated. These correlations will assist in determining if performance measures can be predicted from supervisory ratings.

- The observational checklist of those students who do not reach criterion at the end of the course and at the time of the retention measure will be examined. The checklists will be screened for the type of errors that are made. A summary of the errors may assist trainer designers in future efforts; i.e., if possible, an attempt will be made to trace the errors to design problems, such as level of fidelity.

The results of this study will be used in a number of ways. Primarily, the results will be used to make recommendations regarding the cost and training effectiveness of simulators and associated instructional features for teaching maintenance tasks.

The Air Force SIMSPO will be in a better position to decide which features to incorporate on future trainers based on the results of this study. The cost and training effectiveness data will provide insights on how to restructure the training development process, as well as the cost/benefit tradeoffs for incrementing the simulator's capabilities in terms of instructional features.

Finally, the study will provide a model for future evaluation efforts. A handbook will be designed for the Air Force to assist individuals in designing and conducting training and/or cost effectiveness analyses of maintenance training simulators.

The approach and results of the F-16 SAMT assessment will influence the acquisition, design, utilization, and evaluation of future maintenance training simulators.

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