# COST-EFFECTIVENESS OF MAINTENANCE SIMULATORS FOR MILITARY TRAINING

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ABSTRACT

The cost-effectiveness of maintenance simulators is compared to that of actual equipment trainers for training military maintenance technicians. Maintenance simulators are as effective as actual equipment trainers when measured by student achievement at school; there is no difference in the job performance of students trained either way, according to supervisors' ratings (based on one study). The acquisition cost of maintenance simulators is less than that of actual equipment trainers; they cost less than 60 percent as much if development costs are included and less than 20 percent as much if only unit fabricating costs are considered. Acquisition and use of a maintenance simulator over a 15-year period would cost 38 percent as much as an actual equipment trainer (according to one life-cycle cost comparison). Since maintenance simulators and actual equipment trainers are equally effective and since maintenance simulators cost less, it is concluded that maintenance simulators are more cost-effective than actual equipment trainers. This finding is qualified because it comes from a limited number of comparisons, because effectiveness is based primarily on school achievement rather than on-the-job performance and because it is based primarily on acquisition rather than on life-cycle costs.

## INTRODUCTION

This paper compares the cost-effectiveness of maintenance training simulators and actual equipment trainers for use in training military personnel how to maintain operational equipment. Both types of equipment have been used for training personnel to perform corrective and preventive maintenance at organizational and intermediate levels (Orlansky and String 1981).

Actual equipment trainers have long been used in technical training schools for two significant reasons: (1) they can be acquired simply by ordering additional units of operational equipment already being procured as components of weapon and support systems; and (2) they provide realistic training on the equipment to be maintained after leaving school. Operational equipment can be modified for training by, for example, placing it on a stand and adding power supplies, input signals and controls needed to make it operate in a classroom. In recent years, there has been a trend to use maintenance training simulators rather than actual equipment for training purposes. Maintenance simulators are said to have advantages for use in training such as lower cost, ability to demonstrate a wider variety of malfunctions and more freedom from breakdown in the classroom.

## MAGNITUDE OF THE PROBLEM

Maintenance is a critical aspect of defense planning and operations and costs $18-20 billion each year, including the costs of spare parts, supplies and modifications (Turke 1977, p. 5). According to the General Accounting Office, the Army spends 25 percent ($7 billion in FY 1978) of its annual budget on maintenance; over 200,000 mechanics and equipment operators in the Army have specific unit-level maintenance responsibilities (GAO 1978, p. 1). In the Air Force, maintenance requires about 28 percent of the work force (military and civilian) and costs between $5 and $7 billion annually (Townsend 1980). Labor for repairs is estimated to account for 39 percent of the cost of recurring logistical support of the Air Force A-7D aircraft (Fiorello 1975). Specialized skill training at military schools will cost about $3.4 billion or 33 percent of the cost of individual training in fiscal year 1982 (Department of Defense, Military Manpower Training Report for FY 1982, p.6); the portion attributed solely to maintenance training is not known. The cost of on-the-job training, that follows school training, is also not known.

The three services spent over $5 million in FY 1979 for research and development on maintenance simulators. About $3.7 million (68 percent) of these funds (category 6.4 funds) were for the development and procurement of prototype training equipment. About 30 different maintenance simulators were either under contract or planned for development, as of February 1981.

There are now about 3600 different types of maintenance training devices in the Air Force to support aircraft systems. The Air Force Air Training Command estimates that the current inventory of all maintenance training devices cost $500 million, of which $350 million is for aircraft maintenance alone (Aeronautical Systems Division, 1978). The procurement of maintenance simulators for the F-16 aircraft is estimated to cost about $32 million, including some units to be delivered to NATO countries.

One large industrial contractor has estimated that the Department of Defense will spend over $600 million for maintenance trainers from 1977 to 1985; annual procurements are estimated to reach about $120 million per year by 1984 (Figure 1). The distribution of this procurement, according to type of simulator, is shown in Figure 2. Outside the United States, the procurement of maintenance simulators is estimated to be about $5.5 million per year.

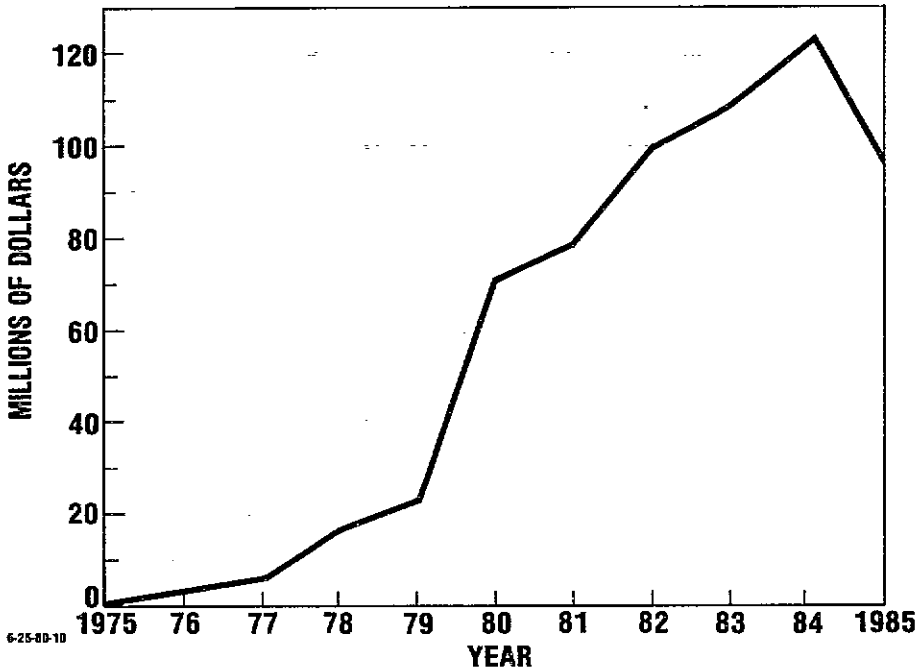


FIGURE 1. Estimated Procurement of Maintenance Trainers by the Department of Defense, 1975-1985 (as of November 1979)

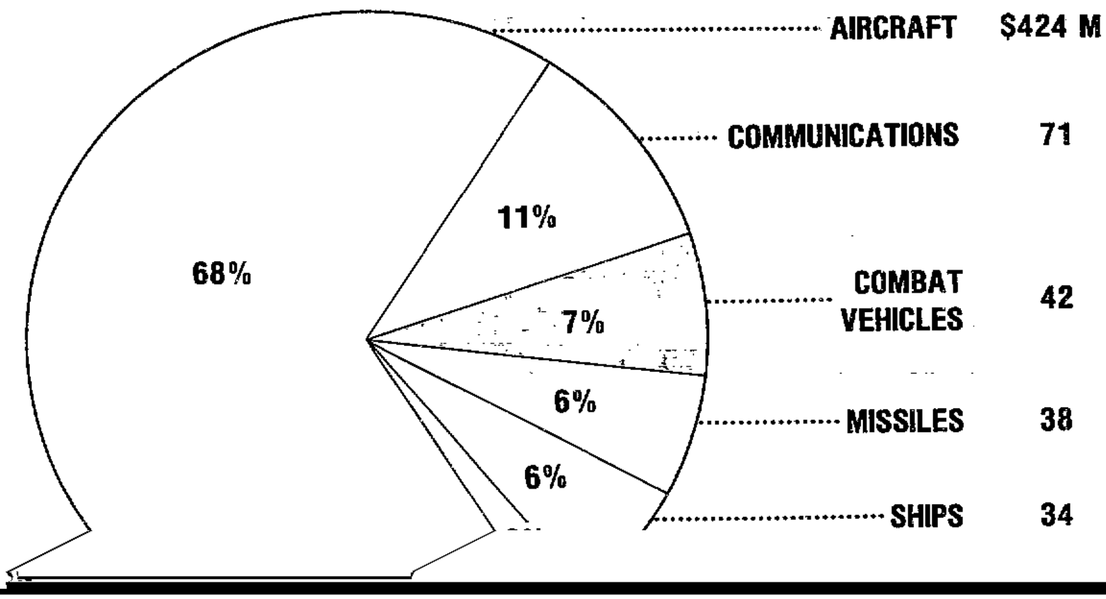


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FIGURE 2. Predicted Procurement of Maintenance Trainers by the Department of Defense, According to Type of Application

The "Electronics-X" study, conducted in 1974, was a major effort to determine the cost and reliability of military electronic equipment (Gates, Gourary, Deitchman, Rowan and Weimer, 1974). Four methods were used to estimate the cost of maintaining electronics equipment each year. The results ranged from $3.4 billion to $6.8 billion with an average of $5.4 billion per year (Gates, Gourary, Deitchman et al., 1974, Vol. II, p. 374). The estimate of $5.4 billion per year for maintenance is about equal to the cost of procuring electronic equipment each year (Gates, Gourary, Deitchman et al., 1974, Vol. I, p. 52). Note that procurement costs relate to acquiring current technology; the maintenance costs relate to systems whose average age is about ten years.

The costs for manpower were estimated by the Defense Science Board Task Force on Electronics Management to account for perhaps as much as 75 percent of the costs of maintaining military electronics equipment; actual costs are unknown due to limitations in the cost allocation system (DSB, 1974, p. 14).

## CHARACTERISTICS OF MAINTENANCE SIMULATORS

Maintenance simulators now under development differ notably in their resemblance to actual equipment, their ability to provide instructional services, and in their complexity and cost. These simulators are often characterized as 2-D or 3-D devices, i.e., as being two- or three-dimensional in their physical form; some simulators contain both 2-D and 3-D components.

The manufacturers of 2-D simulators have developed software packages, computer and support equipment that can be used in a number of different simulations. This has led us to distinguish between, what we call later in discussing costs, "standard" and "non-standard" maintenance simulator systems. Standard systems, whether they are 2-D or 3-D simulators, are likely to cost less than non-standard systems. A 3-D simulator permits "hands on" practice in manual maintenance skills not possible on many 2-D simulators; it also has greater physical similarity to the actual equipment. Whether or not greater physical similarity increases the effectiveness of training is a proper question.

### Advantages of Maintenance Simulators

The advantages of simulators for training maintenance personnel have been recognized for many years (e.g., R.B. Miller 1954, Gagne 1962, Lumsdaine 1960, Valverde 1968, Kinkade and Wheaton 1972, G.G. Miller 1974, Montemerlo 1977, and Fink and Shriver 1978). The major advantage of a maintenance simulator is that, as a training device, it can be designed to provide facilities important for instructing students; in contrast, actual equipment is designed to perform some military function and is not intended to be a training device.

Maintenance simulators can be designed to demonstrate a large variety of malfunctions with which maintenance personnel should be familiar, including those that cannot be demonstrated conveniently on actual equipment trainers or that occur rarely in real life. All modern maintenance simulators incorporate some type of computer support. Thus, the symptoms of many types of complex faults can be stored in the computer and selected simply by a control setting on the instructor's console. Computer-supported equipment can also record what the student does, thereby reducing the need for constant observation by the instructor. The instructor can use information collected by the computer to guide each student; a computer can also assist the student without an instructor's intervention. Records of student performance and achievement can be maintained automatically. Simulators can be made rugged enough to sustain the damage or abuse encountered from students. Thus, they can provide greater reliability and availability in the classroom than is often often possible with actual equipment. Training that would be avoided because of safety reasons, e.g., exposure of students to dangerous electrical currents or hydraulic pressures, can be undertaken with little risk with a simulator. If students using such equipment complete their training in less time, as has often been found with computer-based methods of instruction, there are potential cost benefits due to savings in student time, increased throughput of students and reduced need for instructors and support personnel.

A simulator need not contain all the components found in the actual equipment. Thus, it is often possible to build a simulator that has greater flexibility and capacity for training and costs less than an actual equipment trainer.

### Disadvantages of Maintenance Simulators

There are some disadvantages to the use of simulators. The procurement of maintenance simulators necessarily involves costs to design and build this special equipment, to develop course materials, maintenance procedures, support and documentation. The types of training provided by simulators may not provide the student with all the skills needed to maintain operational equipment, an outcome that seems assured when actual equipment is used for training. A simulator may not be ready when needed for training the initial cadres of a new weapon system because its design and development requires some effort in addition to or at least parallel to that needed for the actual equipment which is already being produced for the new system; modifications in the design of the actual equipment for a new system may also require modifications in the simulator and delay its delivery. If there are many and frequent modifications to the system, the original simulator may have to be redesigned totally at some additional cost, in order to be useful for training.

Data on the effectiveness and cost of maintenance simulators and actual equipment trainers are considered next.

## THE EFFECTIVENESS OF MAINTENANCE SIMULATORS

The purpose of maintenance training, whether with simulators or actual equipment trainers, is to qualify technicians to maintain equipment in the field. In fact, however, the effectiveness of maintenance simulators for training technicians has been compared to that of actual equipment trainers only on the basis of student performance at school and not on the job; there is one exception to this general statement (Cicchinelli, Harmon, Keller and Kottenstette, 1980). The lack of job performance data to validate training applies generally to all types of military training rather than to maintenance training alone.

### Effectiveness of Maintenance Simulators at Schools

We found 12 studies, conducted over the period of 1967 to 1980, that compare the effectiveness of maintenance simulators

the performance of technicians trained with the simulator or the actual equipment trainer. The abilities of the technicians in both groups increased with amount of time on the job.

### Time Savings

The automated and individualized method of instruction that is an inherent characteristic of modern maintenance simulators should be expected to save some of the time students need to complete the same course when given by conventional instruction (Orlansky and String 1979). Such time savings are reported in three of these studies (Parker and DePauli, 1967, Rigney, Towne, King and Moran, 1978 and Swezey, 1979); compared to the use of actual equipment trainers, maintenance simulators saved 22, 50 and 50 percent, respectively, of the time students needed to complete these courses. Although no explanations are offered for these time savings, one could surmise that they are due to such factors as that brighter students can complete a self-paced course faster than one given by conventional, group-paced instruction, that maintenance simulators

| SIMULATOR | COURSE | COURSE LENGTH (STANDARD) | COMPARISONS: SIMULATOR TO ACTUAL EQUIPMENT | | | | | | | REFERENCE |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | NO. OF SUBJECTS(3) | EFFECTIVENESS(1) | | | | ATTITUDE TO SIMULATORS(2) | | |
| | | | | POORER | SAME | BETTER | TIME SAVINGS | STUDENTS | INSTR. | |
| Generalized sonar Maintenance Trainer | Sonar maintenance (special course) | 4 days(3) | 9 | | • | | 22%(4) | Students favorable | | Parker and DePauli, 1967 |
| | Intermediate General Electronics | 4 weeks | 20 | | • | | | | | DePauli and Parker, 1969 |
| EC II | APQ-126 Radar | | 17 | | | | | + | | Spangenburg, 1974 |
| | Mohawk Propeller System | 3 hrs | 33 | | | • | | | | Darst, 1974 |
| | Hydraulic and Flight Control | 32 hrs | 13 | | • | • | | + | – | Wright and Campbell, 1975 |
| | Engine, Power Plants and Fuel | 24 hrs | 13 | • | • | | | + | – | Wright and Campbell, 1975 |
| | Environmental/Utility System | 32 hrs | 9 | | •• | | | + | – | Wright and Campbell, 1975 |
| | APQ-126 Radar | 60 hrs | 15 | | •• | | | 0/+ | 0/+ | McGuirk, Pieper, and Miller, 1975 |
| | | | | | | | | | | Platt, 1976 |
| | | | | | | | | + | + | Biersner, 1975 |
| | Pilot Familiarization, T-2C | 18 hrs | 6 | | | | | | + | Biersner, 1976 |
| | Flight Officer Familiarization, TA-4C | 11 hrs | 30 | | | | | | + | Biersner, 1976 |
| Automated Electronics Maintenance Trainer | FM Tuner | | | | | | | | | Modrick, Kanarick, Daniel, and Gardner, 1975 |
| | Power Control for ALM-64 Test Equip | | | | | | | | | Modrick, Kanarick, Daniel, and Gardner, 1975 |
| | ALM-106B Test Set | | | | | | | | | Modrick, Kanarick, Daniel, and Gardner, 1975 |
| | Visual Target-Acquisition System | | | | | | | | | Modrick, Kanarick, Daniel, and Gardner, 1975 |
| Generalized Maintenance Training System | SRC-20 UHF Voice Command System | | 20 | | | | ABOUT 50% | + | | Rigney, Towne, King, and Moran, 1978 |
| | SPA-61 Radar Repeater | 16 hrs | 10 | | | | | + | | Rigney, Towne, Moran, et al., 1978 |
| Fault Identification Simulator | Hagen Automatic Boiler | 5 wks | 16 | | • | | ABOUT 50% | | | Swezey (in Kinkade 1979) |
| 6883 Converter/ Flight Control Systems Test Station | F-111 Avionics Maintenance | 6 days(5) | 56 | | • | | | + | 0/+ | Cicchinelli, Harmon, Keller, et al, 1980 |

(1)Some studies provide more than one comparison.
(2) favorable. 0 neutral. negative: 0/+ neutral to mildly favorable
(3)Simulator only.

(4)Average of five maintenance tasks in final test.
(5)*Training with 6883 takes 2 days in a 23-week course; 6 days in this special test.*

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FIGURE 3. Summary of Studies on the Effectiveness of Maintenance Simulators, 1967-1980

setup. The student takes a test at the completion of each lesson; the answers, on a sheet, are scored by the computer via an optical reader, which then directs the student to a new lesson or to additional practice on the current one.

CAI and CMI systems are not maintenance simulators but they have been used to provide certain aspects of maintenance training, e.g., knowledge of operating principles, troubleshooting procedures, fault identification, and the knowledge aspects of remove and replace actions (i.e., what the technician should do after a fault is identified rather than perform the task with actual parts). Knowledge about maintenance procedures can be acquired on a CAI and CMI system but this is accomplished with less fidelity and with little of the hands-on experience than can be provided by a maintenance simulator, particularly of the 3-D variety. Some of the new maintenance simulators are essentially CAI systems.

Student Achievement

In a previous study, the authors examined the cost-effectiveness of computer-based instruction in military training (Orlansky and String 1979). Some of the courses on which effectiveness data were available involved instruction similar to that provided on maintenance simulators, i.e., basic electronics, vehicle repair, fire control system maintenance, precision measuring equipment and weapons mechanic. Data on student achievement in these courses are presented in Figure 4; there are 28 comparisons of conventional instruction with CAI and two with CMI. Student achievement in these courses at school with CAI or CMI was the same as or superior to that provided by conventional instruction; the amount of superior performance, when present, was small. This is consistent with what we found for maintenance simulators.

Time Savings

Data on the amount of student time saved by CAI and CMI in these courses, compared to conventional instruction, are shown in Figure 5; there are 30 comparisons. The amount of time saved by computer-based instruction varied from -32 to 59 percent with a median value of 28 percent.

## THE COST OF MAINTENANCE SIMULATORS

Many people believe that the cost of a maintenance simulator is a function of the fact that it is a two-dimensional or three-dimensional device. There is a certain plausibility to this point of view which relates the physical characteristics and complexity of a simulator to its cost. But another important cost factor concerns the number of units that are procured and, thus, the average cost of each unit. In order to deal with the issue of costs, we divided simulators into three classes called standard, non-standard and CAI-like systems.

Standard Systems

This class of maintenance simulators is based on standardization of the physical configuration. Such simulators consist of two elements: one element, called here the "general simulation system" constitutes a generalized and adaptable (but incomplete) simulation capability that can satisfy a wide range of specific training applications. The second element, that tailors the general simulation system to a particular training application, is typically limited to courseware and pictorial or other representations (i.e., the simulation model) of the particular equipment being simulated. Standard systems were the earliest type to be used for maintenance training and are the only class to achieve extensive use. Compared with the other classes of simulators, the standard systems are generally low in cost and limited in terms of the complexity of processes that can be simulated. About 650 units of standard simulators have been procured for about 200 different training applications (most produced by ECC, Burtek, Ridgeway, and Lockheed).

Non-Standard Systems

The outstanding characteristic of non-standard systems is diversity, encompassing different contractors and types of contracts, program purpose, numbers of devices manufactured, physical characteristics, complexity, and cost.

The physical characteristics of the non-standard simulators are diverse and include two- and three-dimensional trainers. There is wide variability in the software. Further, since most non-standard systems typically simulate only one operational system, there is no definitive separation between software and courseware functions. There are now about 17 non-standard maintenance simulator programs that will produce 687 units of 47 unique maintenance simulators, e.g., the Mk 92 Fire Control System, Close-In Weapon System, F-16, MA-3 and 6883 Test Bench. Producers of these simulators include Honeywell, Vought, Applimation, Grumman and RCA.

CAI-Like Systems

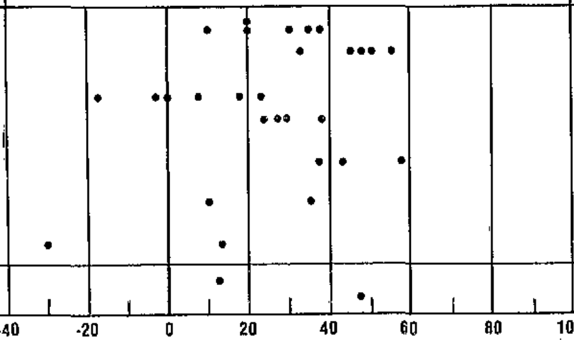
A CAI-like maintenance simulator is a computer-assisted instruction (CAI) system with courseware designed specifically to train maintenance skills. A typical CAI system uses a two-dimensional display (cathode ray tube and/or random access slide or microfiche projector) to present lesson materials (pictures of equipment and the like) under control of a computer that also monitors student progress, prescribes lessons, and scores tests. When

| METHOD OF INSTRUCTION | SYSTEM | SERVICE | LOCATION | STUDENT ACHIEVEMENT AT SCHOOL (compared to conventional instruction) INFERIOR | SAME | SUPERIOR | TYPE OF TRAINING | REFERENCES |
|---|---|---|---|---|---|---|---|---|
| CAI | IBM 1500 | A | SIGNAL C&S | | • • • • | • • | ELECTRONICS | IBM (1968), Longo (1969, 1972) Giunti and Longo (1971) |
| | | N | SAN DIEGO | | | • • • • • | ELECTRICITY | Ford & Slough (1970), Hurlock & Lahey (1971, 1972), Ford, Slough *et al.* (1972) |
| | PLATO IV | N | SAN DIEGO | | • • | • • • • | ELECTRONICS | Stern (1975), Lahey, Crawford *et al.* (1976), Slough and Coady (unpubl.) |
| | | AF | CHANUTE | | • • • • | | VEHICLE REPAIR | Dallman, De Leo *et al.* (1977) |
| | LTS-3 | AF | KEESLER | | • • | • | ELECTRONICS | Harris, Grossberg *et al.* (1972), Keesler AFB (1972, 1973) |
| | IDIIOM | N | DAM NECK | • | • | | FIRE CONTROL TECHNICIAN | General Electric Ordnance Systems (1975), Radsken and Grosson (1975) |
| | PLATO IV | N | DAM NECK | | • • | | FIRE CONTROL TECHNICIAN | General Electric Ordnance Systems (1975), Radsken and Grosson (1975) |
| | | | | TOTAL 1 | 15 | 12 | | |
| CMI | AIS | AF | LOWRY | | • | | PREC. MEASURING EQPT. | Briefing (1978) |
| | | AF | LOWRY | | • | | WEAPONS MECHANIC | Briefing (1978) |
| | | | | TOTAL 0 | 2 | 0 | | |

Source: Orlansky and String (1979)
6-27-80-3

FIGURE 4. Student Achievement at School in Courses Relevant to Maintenance, CAI and CMI Compared to Conventional Instruction

| METHOD OF INSTRUCTION | SYSTEM | SERVICE | LOCATION | STUDENT TIME SAVINGS (compared to conventional instruction) | TYPE OF TRAINING | REFERENCES |
|---|---|---|---|---|---|---|
| CAI | IBM 1500 | A | SIGNAL C&S | see chart | ELECTRONICS | IBM (1968), Longo (1969, 1972) Giunti and Longo (1971 a&b) |
| | | N | SAN DIEGO | | ELECTRICITY | Ford & Slough (1970), Hurlock & Lahey (1971, 1972), Ford, Slough *et al.* (1972) |
| | PLATO IV | N | SAN DIEGO | | ELECTRONICS | Stern (1975), Lahey, Crawford *et al.* (1976), Slough and Coady (unpubl.) |
| | | AF | CHANUTE | | VEHICLE REPAIR | Dallman, DeLeo *et al.* (1977) |
| | LTS-3 | AF | KEESLER | | ELECTRONICS | Harris, Grossberg *et al.* (1972), Keesler AFB (1972, 1973) |
| | IDIOM | N | DAM NECK | | FIRE CONTROL TECHNICIAN | General Electric Ordnance Systems (1975), Radsken and Grosson (1975) |
| | PLATO IV | N | DAM NECK | | FIRE CONTROL TECHNICIAN | General Electric Ordnance Systems (1975), Radsken and Grosson (1975) |
| CMI | AIS | AF | LOWRY | | PREC. MEASURING EQPT. | Briefing (1978) |
| | | AF | LOWRY | | WEAPONS MECHANIC | Briefing (1978) |




Source: Orlansky and String (1979).
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FIGURE 5. Amount of Student Time Saved in Courses Relevant to Maintenance, CAI and CMI Compared to Conventional Instruction

adapted to maintenance training, the CAI features are retained, and the trainer may also employ three-dimensional versions of equipment. Examples of such systems are the Navy Electronic Equipment Maintenance Trainer and the Army Maintenance Training and Evaluation Simulation System. Insufficient cost data were available on CAI-like maintenance simulators and they are not discussed further.

## Costs of Maintenance Training Simulators

We learned, to our regret, that the data now available on standard systems are insufficient to analyze their elements of cost and to relate these cost elements to the physical and performance characteristics of the trainers. In effect, it is now difficult or impossible to identify the major cost distinctions (e.g., between recurring and non-recurring costs, between development and fabrication, between hardware and software) that allow characteristics of the simulator to be related to the total cost of the simulator program.

Data from nine contracts for standard simulators were reviewed, and the information they contain is shown in Figure 6. These contracts involve the development of 67 different models of simulators and the delivery of a total of 444 units. The figure shows average contract cost per delivery (total contract value divided by the number of trainers procured) vs the number of trainers procured in each contract. These simulators ranged in unit

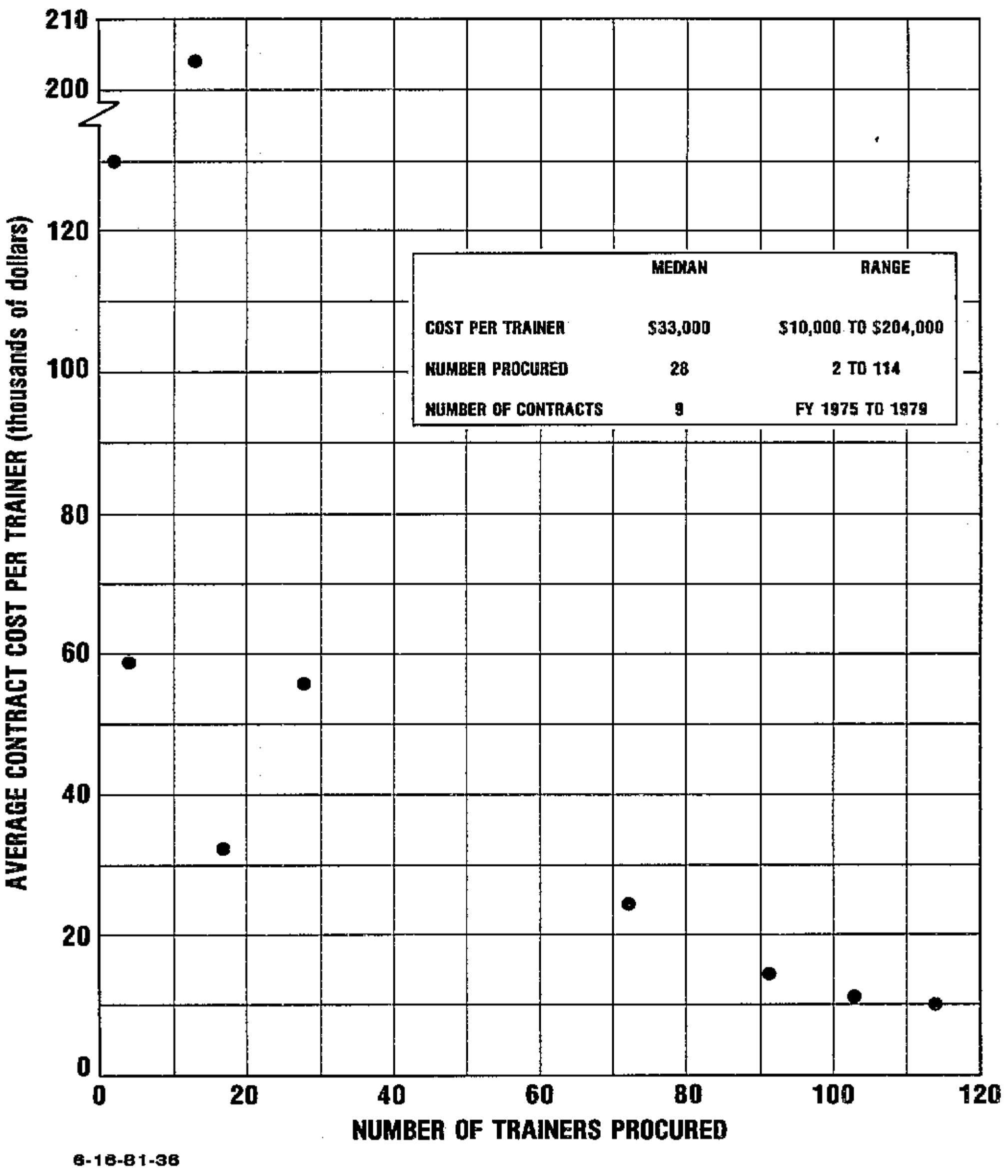


FIGURE 6. "Standard" Maintenance Simulators: Average Cost Per Trainer vs. Number of Trainers Procured

cost from about $10 thousand to $204 thousand each, with a median cost of about $33,000. As we would expect, the unit cost is reduced as the number of units in each contract increases. However, these simulators are not a homogenous sample; they vary in their complexity, physical and performance characteristics. Therefore, caution is advised in using the data in this figure.

The cost of 13 non-standard maintenance simulators is shown in Figure 7. The estimates are normalized to show recurring production costs adjusted to reflect a production quantity of one; costs of development and test are not included. These simulators range in cost from $100 thousand to $4.5 million; the median value is $900 thousand.

The non-recurring costs account for a large portion of the total program costs of non-standard maintenance simulators--over 70 percent when only unit is fabricated and about 50 percent when five or six are fabricated (Figure 8). Software and courseware account for 10 to 45 percent of total program costs (Figure 9).

## COST-EFFECTIVENESS OF MAINTENANCE SIMULATORS

We found that student achievement at school is about the same whether students are trained with maintenance simulators or with actual equipment trainers. Therefore, the relative cost-effectiveness of maintenance simulators and actual equipment trainers depends on how much each costs.

We have just shown what maintenance simulators cost; next, we must compare the costs of simulators and of actual equipment trainers. But note that the data on maintenance simulators refer only to procurement costs. These data do not include the costs of using these simulators, such as for instructors, student pay, support and travel, maintenance of the training equipment and management of the school. There is one life-cycle cost comparison that we will consider separately. The cost comparison that follows is incomplete because it is based only on acquisition costs.

The cost of an actual equipment trainer is the production cost of one unit of equipment under procurement for some military system; this value does not include the costs of research, development, test and evaluation (RDT&E). Adapting a component of an operational system for use in training, such as by adding power, special inputs and controls, may require some additional costs attributable to training.

We were able to get relatively complete data, useful for comparative purposes, on both maintenance simulators and actual equipment trainers, for only 11 cases; comparisons were not possible for some recently developed maintenance simulators where actual equipment trainers had not been used previously for training. Some of the simulators are prototypes, rather than production units; data on these simulators include the costs of research and development. The costs of research and development should be removed

| Trainer | Cost $(000) |
|---|---|
| AN/TPS-43 Ground Radar | 100 |
| Trident Air Conditioner | 135 |
| Trident High Pressure Air Compressor | 140 |
| F-111D Avionics Test Bench (2-D 6883) | 395 |
| A-6E TRAM | 475 |
| MA-3 Generator/Constant Speed Drive Test Stand | 525 |
| AWACS Radar System | 900 |
| F-111D Avionics Test Bench (3-D 6883) | 920 |
| A-7E Heads-Up Display Test Bench | 1295 |
| F-4J/N (AT Trainer) | 1540 |
| AWACS Navigation/Guidance System | 2460 |
| Trident Integrated Radio Room - Maintenance Trainer | 2625 |
| Trident Integrated Radio Room - Operator/ Maintenance Trainer | 4465 |

FIGURE 7. Acquisition Costs of 13 Non-Standard Maintenance Simulators (Normalized to Include Recurring Costs for a Production Quantity of 1)

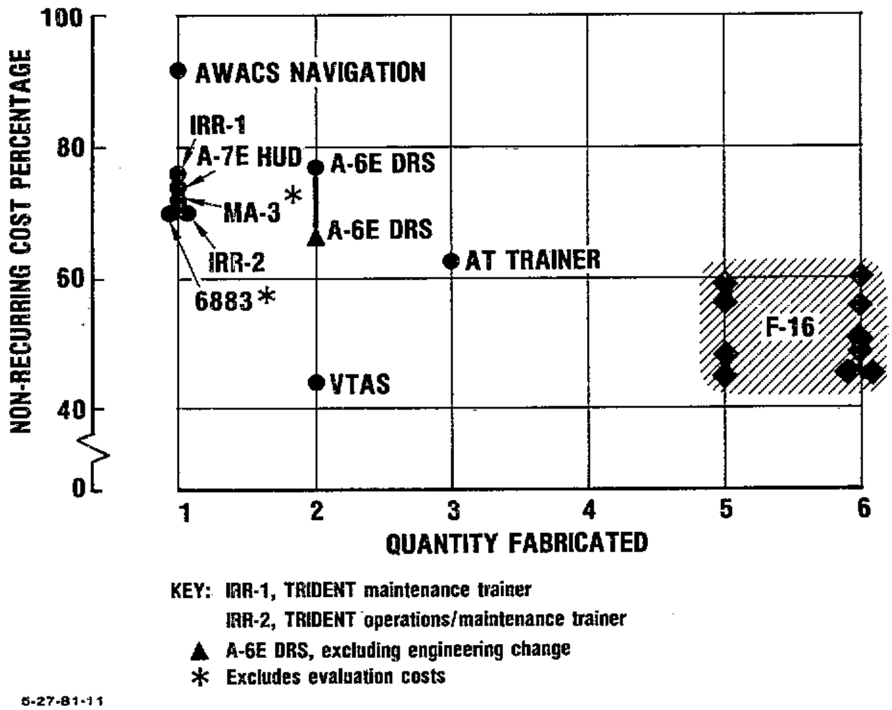


FIGURE 8. Non-Recurring Cost as a Percent of Program Total Cost According to Quantity Fabricated

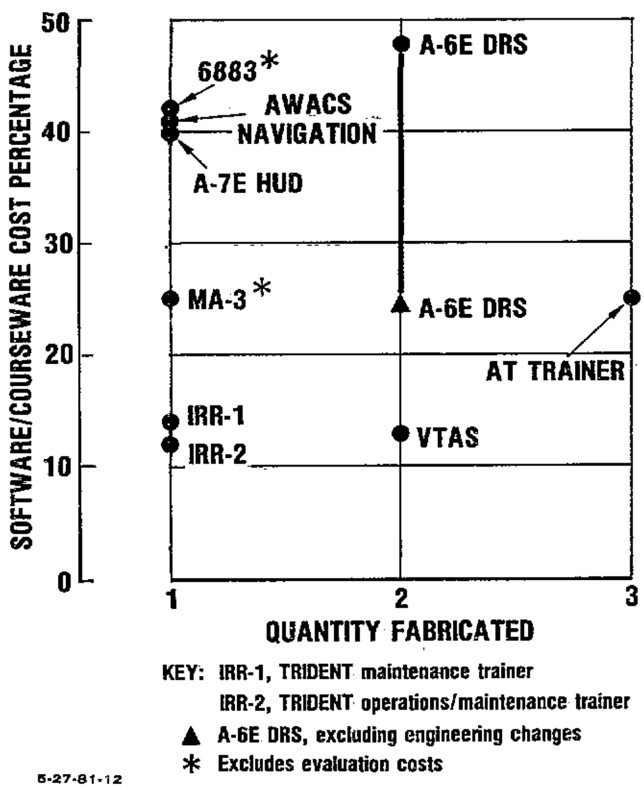


FIGURE 9. Software/Courseware Cost as a Percent of Program Total Cost, According to Quantity Fabricated

in order to make a fair comparison of maintenance simulators with actual equipment trainers which, as noted above, are production items and exclude such costs. The number of maintenance simulators procured could also influence the cost of a single unit; this varied from 1 to 36.

We decided to use estimates which would bracket the cost of one maintenance simulator within high and low limits. These were:

> High cost estimate: Total production costs adjusted to reflect a production quantity of one; this includes the costs of research and development but not of test and evaluation. We call this the "Simulator Normalized Program Cost".

> Low cost estimate: The cost of producing a follow-on maintenance simulator after the costs of RDT&E; prototypes and manufacturing facilities have been accounted for. We call this the "Simulator Unit Recurring Fabrication Cost."

The high cost estimates are shown in Figure 10. The ratio of simulator/actual equipment trainer costs is 0.60 or less for seven cases cases (range 0.25 to 0.55). There are four cases where this ratio varies from 1.60 to 4.00 (VTAS, MA-3, AT Trainer and AWACS). We believe these data are suspect for one or more of the following reasons: the costs of the operational equipments (some of which are relatively old) may have been considerably underestimated; the costs of the simulators, some of which are designed for use in research, may be high because they include capabilities not needed for routine training. For these reasons, we decided to accept 0.60 as an upper limit for the relative cost of a maintenance simulator compared to an actual equipment trainer.

The low cost estimates, based on the recurring cost of these simulators, are shown in Figure 11. Nine of the 11 cases fall at 0.20 or lower; the range is 0.03 to 0.19. The two outlyers (VTAS and MA-3) are regarded as atypical for the reasons set forth above.

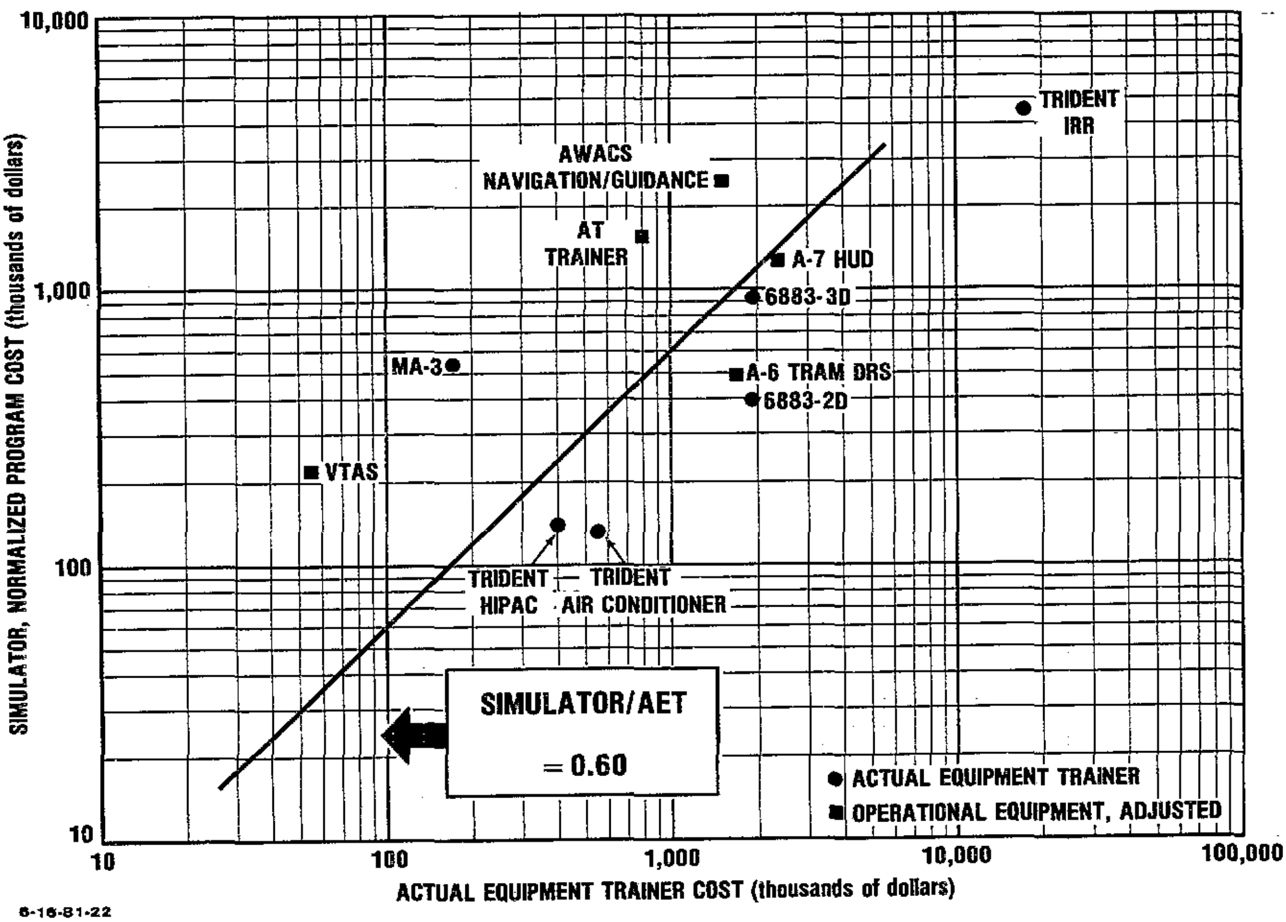


FIGURE 10. Relation Between Actual Equipment Trainer and Simulator Normalized Program Costs

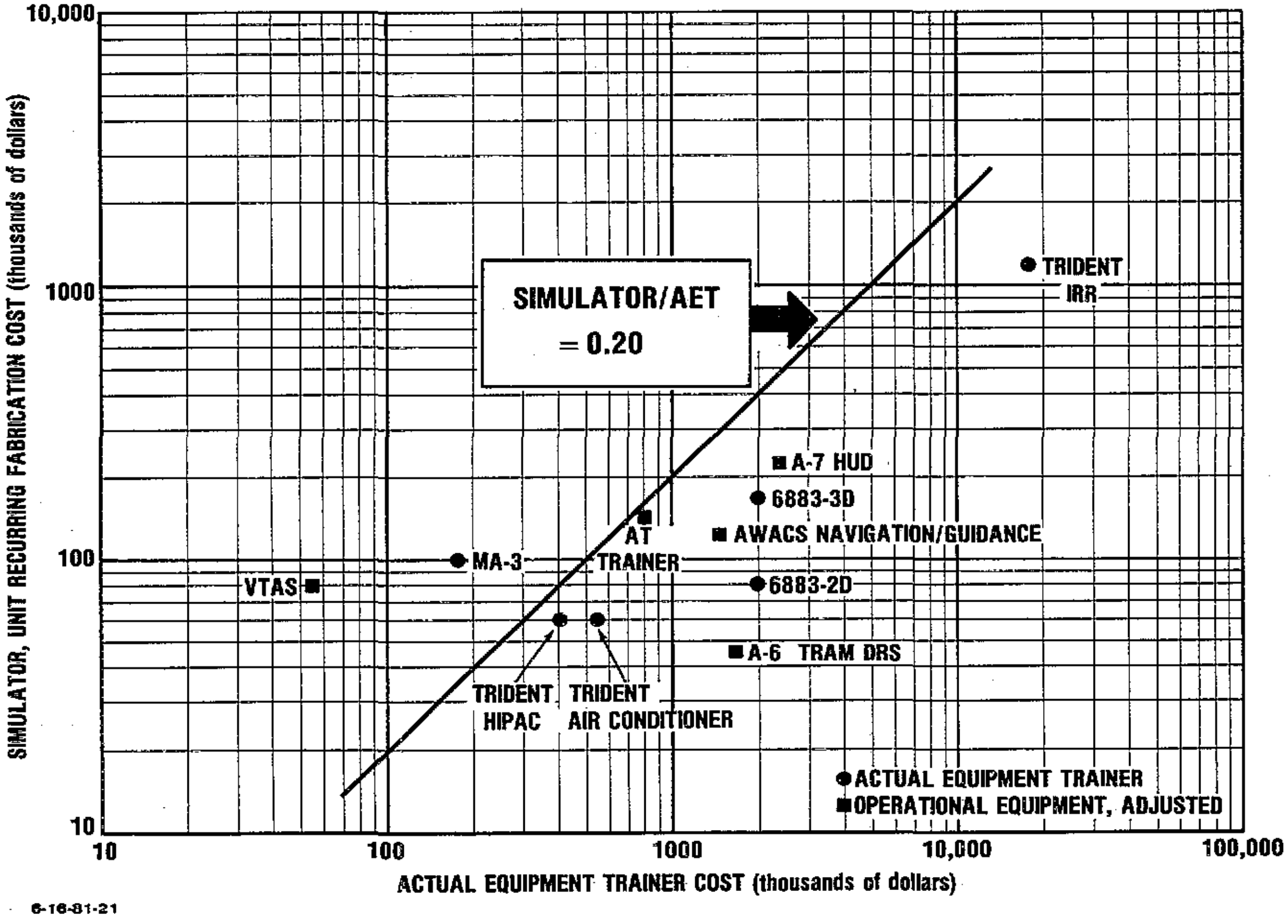


FIGURE 11. Relation Between Actual Equipment Trainer and Simulator Recurring Fabrication Costs

We conclude, therefore, that the acquisition costs of simulators generally fall in the range of 20 to 60 percent that of actual equipment trainers. These are very conservative estimates.

The cost-effectiveness of a maintenance simulator on a life-cycle basis has been evaluated only in one case, that of the Air Force 6883 Test Stand 3-Dimensional Simulator and 6883 Actual Equipment Trainer (Cicchinelli, Harmon, Keller and Kottenstette, 1980). The three-dimensional simulator and actual equipment trainer were equally effective when measured by student achievement at school; supervisors' ratings showed no difference between the job performance of students trained either way for periods up to 32 weeks of experience after leaving school.

The life-cycle cost comparison of simulator and actual equipment trainer is shown in Figure 12. Costs were estimated in constant 1978 dollars over a 15-year period and discounted at 10 percent. The results show that the total cost per student hour was $23 for the simulator and $60 for the actual equipment trainer, i.e., 38 percent as much for the simulator for all costs over a 15-year period. The simulator cost less to procure ($595 thousand vs $2105 thousand, or 28 percent as much) and less to operate ($1588 thousand vs $3367 thousand or 47 percent as much) over a 15-year period.

Therefore, maintenance simulators are more cost-effective than actual equipment trainers.

## DISCUSSION

The finding that maintenance simulators are more cost-effective than actual equipment trainers is necessarily qualified by the limited nature of the data from which it is derived. Effectiveness, as used here, is based on performance demonstrated at school rather than on the job. Cost, as used here, refers to the initial costs of acquiring training equipment and does not include the costs associated with the long term use of simulators or of actual equipment for training, e.g., maintenance and upkeep, instructors and support personnel, student pay and support. In the one case where a life-cycle cost comparison

| Item | (Thousands of dollars) Actual Equipment | Simulator | Simulator/ AET (%) |
|---|---|---|---|
| Acquisition | 2105 | 595 | 28 |
| Recurring costs | 3367 | 1588 | 47 |
| Total | 5472 | 2183 | 40 |
| Net present value (1978 dollars) | 3896 | 1501 | 39 |
| Cost per student hour | 60 | 23 | 38 |

FIGURE 12. 15-Year Life-Cycle Costs of 6883 Test Stand 3-Dimensional Simulator and Actual Equipment Trainer

was made, total cost per student hour over a 15-year period for the 6883 Test Stand 3-Dimensional Simulator was 38 percent as much as for the actual equipment trainer. Both were equally effective as measured by tests at school and by supervisors' ratings of performance of technicians on the job after leaving school.

The data on the cost and effectiveness of maintenance simulators have not been collected in a systematic manner. Therefore, there is no basis at present for making trade-offs between the effectiveness and cost of different types of maintenance simulators on such issues as two-dimensional vs three-dimensional design, the complexity of maintenance simulators (in such terms as number of malfunctions and instructional procedures), the extent to which simulators should provide a mixture of training in general maintenance procedures applicable to a number of different equipments or for maintaining only specific equipments, and the optimum combination of maintenance simulators and actual equipment trainers for training technicians at school.

There have been too few studies on the amount of student time saved with the use of maintenance simulators. There have been no studies on whether the use of maintenance simulators influences the amount of student attrition at school. There have been no studies to collect objective measures of performance of maintenance technicians on the job after training either with simulators or actual equipment trainers.

Maintenance simulators now under development are only beginning to use recent technological advances such as videodiscs, automated voice input and output, and miniaturization sufficient to make them readily portable. There has been more talk than action about such possibilities. Reductions in size would make it possible, as well as convenient, to use maintenance simulators for refresher training near job sites and for performance evaluation and/or certification of maintenance personnel on an objective basis in operational environments. Extreme reductions in size would make it possible to use maintenance simulators as job aids in performing maintenance on operational equipment, thus assuring a close link, not yet available, between facilities used for training at school and for performance on the job. There is a small but probably insufficient effort along these lines.

## CONCLUSIONS

1. Maintenance simulators are as effective as actual equipment trainers for training military personnel, as measured by student achievement at school and, in one case, on the job. The use of maintenance simulators saves some of the time needed by students to complete courses, but data on this point are limited. Students favor the use of maintenance simulators; instructors are favorable, neutral or negative to the use of simulators in about equal amounts.

2. The acquisition cost of maintenance simulators varies from 20 to 60 percent that of actual equipment trainers, for cases where complete cost data were available. The higher value includes the costs of research and development needed to produce one unit; the lower value includes only unit recurring fabrication costs. One life-cycle cost estimate shows that purchase and use of a simulator would cost 38 percent as much over a 15-year period as it would for an actual equipment trainer.

3. Maintenance simulators are as effective as actual equipment trainers for training maintenance personnel. They cost less to acquire. Therefore, maintenance

simulators are cost-effective compared to actual equipment trainers.

4. The conclusions to this paper must be qualified by the fact that they are based on limited and often incomplete data. There is a need for hard data that compare maintenance simulators to actual equipment trainers in the following areas: life-cycle costs, on-the-job performance, and student attrition at school. There is also a need to compare the cost and effectiveness of simulators that vary in complexity of design, e.g., two- and three-dimensional simulators and types of instructional features.

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