Technical Note

1975-23

R. C. Butman

Computer Assisted Instruction; Some Techno-Economic Factors

1 April 1975

Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
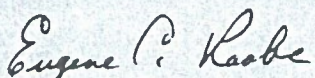
LEXINGTON, MASSACHUSETTS

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Eugene C. Raabe, Lt. Col., USAF
Chief, ESD Lincoln Laboratory Project Office

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LINCOLN LABORATORY

COMPUTER ASSISTED INSTRUCTION;
SOME TECHNO-ECONOMIC FACTORS

R. C. BUTMAN

Group 27

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ABSTRACT

Successful implementation and use of any CAI system requires that careful attention be given to the costs and benefits of CAI in the chosen environment. This paper considers costs as a function of system utilization factors and size and geographic dispersion of the student population. Comparisons are made between three generic CAI systems — a system with several thousand terminals, a system with 128 terminals and a system where the computer is integral with each terminal.

CONTENTS

SUMMARY

Most papers describing CAI systems concentrate on hardware costs, with some sketchy data on courseware development costs. Little information is available on supervision and maintenance costs, on the size of the student body required to utilize a given system efficiently, and the student flow rates required to amortize courseware development over a reasonable period of time.

In this paper, the costs and utilization problems are examined for three generic systems; one with several thousand terminals per computer, one with 100 or so terminals per computer, and one with one terminal per computer ("stand alone systems").

Based on cost assumptions which the author believes to be reasonable, the following statements may be made:

1. CAI maintenance and instructor costs per terminal hour will be equal to or greater than hardware costs.

2. Costs per terminal hour of a partially utilized system will be significantly higher than costs for a fully utilized system. Cost per terminal hour of a several thousand terminal system which has only 1/4 of its terminals installed will be twice that of the fully implemented system.

3. A system which is scheduled to operate 2000 hours per year requires the continuous presence of a

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student body which is 10 times the number of terminals,* if average student use is 200 hours per year. Since 200 hours is almost 50% of the contact time in a year for the average college student, one would estimate less than 200 hours per year use, and an even larger student body. In a military training environment, contact time is greater (nearer 1440 hours per year) and scheduled computer time could easily be 3000 hours. Under these circumstances, 50% of contact time under CAI leads to a requirement for a continuously present student body about four times the number of terminals.

4. Courseware development costs are high and must be amortized over more than 1000-2000 users in order to make courseware costs reasonable. If courseware development costs $3000 per hour, 2400 students would have to use the material before courseware costs per hour become equal to an average hardware operating cost (including maintenance and supervision). Courses for CAI must be selected for high flow rate and/or stable content, unless unusual circumstances prevail (e.g., a requirement for instruction in remote areas where conventional teaching is exorbitantly expensive).

5. Small CAI systems are easier to utilize fully than large systems and do not require expensive communications between terminal and computer.

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* Queuing/scheduling problems will modify this figure.

6. The high cost of developing programmed materials (e.g., programmed texts) and the cost of supervision of use of those materials makes them a less attractive substitute for CAI than one might intuitively believe.

It follows that the CAI environment must be carefully selected if the advantages of the medium over conventional classroom instruction are to be realized.

The author recognizes that many of the cost estimates used in this paper will be questioned by potential CAI users and by developers of CAI. A major objective of the paper is, in fact, to stimulate questions about and discussions of costs of using CAI systems in various environments. Greater attention needs to be given to overall systems costs and benefits. Comparisons of basic CAI hardware costs with the cost of conventional teaching are inadequate and may be misleading.

INTRODUCTION

The rising cost of training has led to the intensive study of and experimentation with training techniques designed to decrease costs while maintaining current high standards of performance in graduates. Stated in general terms, the problem is one of maximizing learning while minimizing costs. Factors which affect costs include the numbers and level of skills to be learned by any given individual, the entry skill level(s), the flow rate and total number of trainees, and the constraints, if any, imposed by the environment.

Costs may be reduced in a number of ways. The curriculum may be restructured to eliminate irrelevant material, thereby reducing time required to acquire a given skill. Instruction may be individualized so as to decrease the average time required for a group of students to acquire a skill. Travel may be eliminated. Student/instructor ratios may be increased arbitrarily or with the aid of technology.

Large scale use of educational technology, specifically some form of CAI, has long been suggested as a means for decreasing training costs. Experiments, demonstrations, and field trials have shown that computer assisted instructional systems can decrease average learning time and increase student teacher ratios. However, the high capital investment associated with the introduction of these systems, coupled with a degree of skepticism about costs and benefits have deferred substantial commitment to any new system.

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It is the purpose of this paper to examine some of the techno-economic factors associated with the use of CAI, for it is the author's opinion that inadequate attention has been given to these factors.

Before getting into an analysis of economic factors, it is appropriate to take note of some of the considerations involved in the introduction of CAI into any system, some general performance characteristics, and to describe in some detail the generic forms of CAI which are to be considered.

As each new training requirement arises and as each old requirement comes up for review, a decision is made with respect to the most efficient instructional technique to be used. This decision may be made at a relatively low level if the number of students is small and/or the system wide implications are minimal. In such cases, old approaches tend to be perpetuated even though new and more efficient training techniques may exist. The difficulty is that new techniques may be efficient only if they are introduced on a large scale. This is particularly true of technological assists to instruction such as CAI.

The requirement for large scale use for low cost does not necessarily mean that a single user or school must have a large scale application. It does mean that for any given CAI system, there must be enough users to amortize hardware and courseware development. This suggests that the system which can operate efficiently in the greatest variety of environments (e.g., conventional schools, as an aid to on-the-job-training, as a support mechanism for continuing education) will have the greatest chance of satisfying a large number of users. As the number of users increases, the cost of both hardware and courseware will decrease, since developmental costs are amortized over a larger and larger group and production becomes more efficient.

One must also recognize that a CAI system will be required to interface with other instructional systems and with a variety of management systems. These interfaces need not be a source of trouble if adequate attention is given to them in the CAI system design and implementation phases. The interface with other instructional systems must be designed so that as the student moves from CAI to another medium and back, his skill acquisition is transient free. Shifting from medium to medium without transient is primarily a matter of good curriculum design. As an aside, one may speculate that with careful orchestration of media, those transients which do occur, may be beneficial -- in effect, producing a programmed Hawthorne effect.

The second interface is between the instructional system and the management system. All learning systems must be set up so that information on student progress can be analyzed easily and used as a basis for further learning or job assignments. CAI is basically well suited to provide such information in a form which can be easily analyzed.

In this connection, it is important to decide specifically what kind of information is needed and for what purpose. With the aid of a tape or disk recorder, student progress can be monitored on a minute to minute basis if required. Other techniques might be employed to keep daily or weekly records of progress. Minute by minute records can be used: (1) to adjust the student's path through the material, skipping where possible, providing remediation if required, (2) to provide data which can be used to improve the lesson material. Material never accessed may be eliminated, material which is troublesome - as evidenced by an excess amount of time required to complete - may be rewritten. Data collected at more infrequent intervals, weekly for example, may be used to keep track of rate of progress but it will be of less value than the minute by minute record in diagnosing student problems or lesson inadequacies.

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It is the intent in the descriptions of CAI systems which follow to provide a background for the comparison of implementation/utilization problems and cost factors associated with these three systems. It will be assumed that courseware development, hardware maintenance, and instructional effectiveness are essentially the same for all three systems. This assumption is made in order to separate the factors under consideration from the less well defined arguments supporting a particular type of display, level of computational support, courseware philosophy or material preparation technique.

The generic CAI systems of major concern are:

(1) Systems with thousands of terminals controlled by a large central computer. The University of Illinois PLATO (Programmed Learning According To Need) system is the only known existing example of such a system.

(2) Systems with one hundred or so terminals controlled by a moderate sized computer. The Mitre Corporation's TICCIT (Time-Shared Interactive Computer Controlled Information Television) is one of several such systems.

(3) Systems in which the student terminal incorporates its own (micro) computer. The Lincoln Training System (LTS) and the Digital Equipment Corporation's CLASSIC are examples of such a system.

1. A large CAI system (PLATO).[1]

PLATO uses a large (CYBER73) central computer to manage up to 4000 terminals and to provide on-line computation for students as part of the CAI system.

Communication from computer to terminal is through a 1200-bps channel to local and dispersed remote sites.

The cost per terminal hour of a multiterminal CAI system is dependent on the number of terminal hours per year used and on the geographic dispersion of the students. The greater the terminal usage and the smaller the geographic dispersion of users, the cheaper the service. If one assumes that the 4000 terminals are activated, that each one is used 8 hours per day, and that students would spend an average of no more than four hours per day at a terminal, then 8000 students must be available for several years in order to amortize the capital investment and realize the predicted cost per terminal hour. It should be noted that the student flow with any CAI will be greater than with conventional instruction because of the higher efficiency of CAI. A course which normally requires 18 weeks to complete may be expected to require only 15 weeks for an average student if he spends half of his course time at a CAI terminal. Therefore, a school would have to run 3.46 instead of 2.9 18-week courses per year to keep the terminals fully occupied given 8,000 students continuously in attendance. This implies 8000 x 3.46 or 27,600 course students per year. If students spend only two hours per day at the terminal under CAI, then a student body of 16,000 x 3.46 or 55,200 course students per year, is required to fully utilize the system. If continuing education is the main interest, an even greater student body is indicated for the average time at the terminal will probably approximate no more than 10% of the student's working time. With low terminal use per student, geographical dispersion becomes a greater concern, for the larger numbers of students will unquestionably be spread over a greater area -- thus leading to greater communications costs. Use figures and the size of the student body are of importance to other CAI systems but PLATO is unique in that the smallest module requires such a large number of terminals (4000) for full operation.

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The requirement for controlling 4000 terminals also impacts on the software/courseware design and on the flexibility of courseware availability to a given student. PLATO, like all systems, has a finite central file management capacity, and can therefore manage a finite number of terminals and a finite number of course segments. Forty five hours of instruction -- a standard semester course -- or three hours per week for fifteen weeks might have 180 segments (15 minutes each) which are called into active memory as required by a student. Given the PLATO limits of 200 active 15-minute segments, it follows that the equivalent of only one full course can be available simultaneously to the 4000 users and that an average of 20 students must be working on identical segments of the course. Figure 1 indicates the situation for varying numbers of students and course segment availability.

One concludes that the CAI system which is operated with a large central computer will serve best a large non-fluctuating student population which is geographically concentrated, and which does not require a great diversity of course segments to be available simultaneously. This must be considered seriously in any CAI system where such limits occur, for free choice of study, both in time and subject matter is one of the major advantages which CAI can, in principle, afford.

2.   A Cluster CAI System (TICCIT)[2]

The TICCIT system is a medium size (128 terminal) CAI system designed to operate in a single geographic location under the control of a Nova 800 computer. The system does not provide computational power to the students; it relys on key inputs which are matched with stored answers. The student terminal uses a conventional television receiver as the display device.
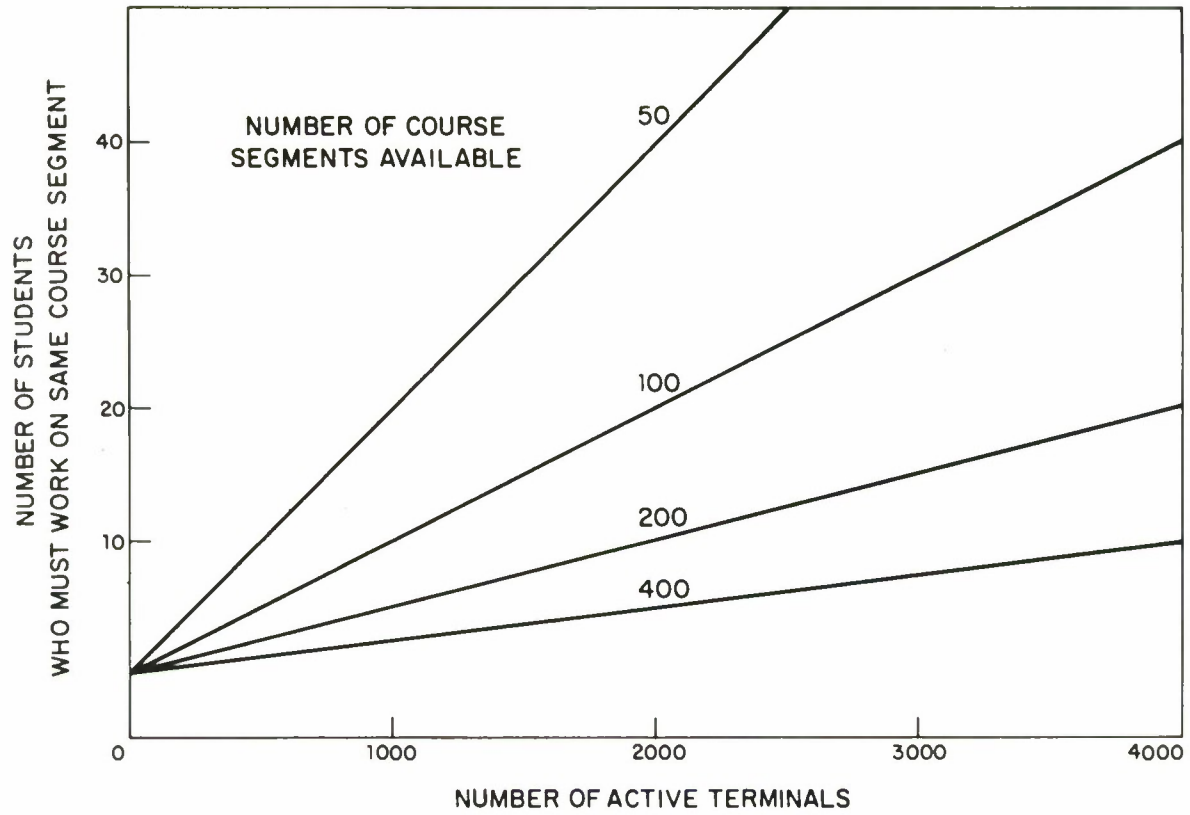
Fig. 1.   Number of Students per Available Course Segment.

TICCIT is best suited for use in a limited geographic area such as a college campus with student populations in excess of 250 students enrolled for the full year if half time use of CAI is contemplated or proportionately larger than 250 if less than half time use is to be the norm.

Since the minimum module size is 128 terminals, system efficiency may be low when modules are added or removed unless the student body is actually well in excess of the minimum 250, so as to minimize round off problems which occur when the central computer capacity does not match demand.

3. Stand Alone Systems (LTS)[3]

The LTS is at the opposite end of the spectrum from PLATO. Each LTS terminal operates independently, using its own microcomputer to manage the lesson. Stand alone operation of a CAI terminal has been possible only since the advent of inexpensive micro-computers. The LTS uses an MCS-4 microcomputer to select and display visual images which are stored on microfiche. A recording technique developed for the LTS also permits storage of audio and lesson control logic on the fiche.

LTS does not in its basic format support computation but it will accept and check number inputs, group item selections, simple and ordered multiple choice, and will respond to a number of special purpose input keys.

Since there is no need for any connection to a central computer, there is no need to cluster a specific number of LTS consoles in one place except to minimize the logistics of maintenance and management.

SYSTEM COSTS

The cost per terminal hour of a CAI system is a function of the cost of hardware, courseware development, programming, hours of utilization per year, number of terminals installed relative to the total number which can be managed by the central computer, supervision, and maintenance. The following sections examine these component costs and terminal utilization problems and develop a picture of how they vary with increasing use, and how they compare with conventional classroom costs.

CAI Hardware and Maintenance Cost

Estimates of CAI hardware and maintenance costs vary widely. Three equipment costs have been chosen here which cover a range of estimates for the basic hardware. This parametric approach is chosen because none of the three systems under consideration have matured to the point where precise cost estimates for production quantities can be made. The basic cost per terminal estimates used here span the range of estimates made by CAI developers.

Basic equipment

	System A	System B	System C
cost per terminal*	$ 10,000	$ 5,000	$ 2,000
Interest 8% - 7 years	3,500	1,750	700
with straight line payoff Total	$ 13,500	6,750	2,700
Cost per hour; 2000 hours per year, 7 years	$ .96	$ .48	$ .19
Round off to:	$ 1.00	$ .50	$ .20

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* includes allocated fraction of computer

Maintenance costs of hardware:

One man services 50 machines:

Salary 12.5K/year   100% overhead

$$\frac{25,000/\text{year}}{2000 \times 50 \text{ machine hours/year}} = \$.25 \text{ per terminal hour}$$

Supervisory costs:

One supervisor/instructor supervises 40 students. Salary 14K/year, 100% overhead. Actual work year, 1400 hours (48 weeks, 30 hours each).

$$\frac{28,000}{1440 \times 40} = \$.486 \approx \$.50 \text{ per terminal hour}$$

Totals:

	A.	B.	C.
Machine cost =	$ 1.00	$ .50	$ .20
Maintenance =	.25	.25	.25
Supervisory =	.50	.50	.50
Total =	$ 1.75	$ 1.25	$ .95

Note that the cost of maintenance and supervision is high enough so that the basic machine cost is less significant than one might expect.

Building overhead costs are ignored, since it is assumed* that those costs are the same for CAI or conventional teaching, so in a comparison of conventional vs CAI, overhead disappears. Note that communications costs have not been included; they

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* This assumption must be examined carefully when the point of detailed comparison is reached, for there may be costs for extra power, air conditioning, and other special facilities associated with some CAI installations.

are considered separately in a later section.

Courseware Costs

Estimates of courseware costs vary widely. A figure of 100 hours of initial
preparation per hour of terminal time is an accepted norm. With nominal labor
charges plus overhead, a figure of $3000 per hour is probable. Curves here will be
plotted for $1000 and $3000. There will also be some charge for maintenance of
courseware -- that is, revisions prompted by changing student requirements,
by changing technology, or by the discovery of a more efficient course plan or in-
structional strategy. These costs are difficult to predict but for this discussion a
charge of .01% of the initial preparation cost per use is suggested for maintenance
and materials. This is equivalent to saying that after 10,000 uses a completely
new edition of the material will have evolved. For initial courseware preparation
costs of $3000, the per hour cost for revisions is $.30 per terminal hour ($3000 x 10^{-4}),
and $.10 for an initial preparation cost of $1000.

Conventional Classroom Costs

Conventional classroom costs are made up of instructor salaries plus overhead.
It is assumed that a typical instructor's salary for a technical subject is $12,000,
that overhead is 100%, that he teaches 20 contact hours a week for 40 weeks, and that
preparation work is included in his responsibilities. Cost per instructor hour, is
therefore, $\frac{24,000}{800}$ = $30 per hour. That is $3.00 per hour for a class of
10; $1.50/hour for a class of 20. The student may be expected to buy a $15.00 book
for a course for a $.30 per hour charge, so cost per student hour will be increased by
that much, resulting in a per student hour cost of $3.30 for a class of 10 and $1.80 for a
class of 20.

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In some training environments, a different situation may exist. In military training, for example, courseware development is the responsibility of a development team, not the classroom instructor. Costs for courseware development appear separately and may well approximate the cost of CAI courseware development. A later section on programmed instruction (PI) discusses the cost of non CAI courseware and though that section is concerned principally with PI, the cost of special development for conventional instruction in a military environment may not be significantly different. Another feature of military training is that course development costs per student may be much higher than in civilian schools, for there are some training requirements in the military which must be met even though course development costs are high. These requirements are generally associated with the operation of large unique high technology systems.

Comparison of CAI and Conventional Classroom Instruction

Figure 2 is a graph of cost per student hour as a function of total student hours for a 50-hour course. For conventional instruction, costs remain essentially constant, for it is assumed as noted above that preparation and revision are continuous processes carried on by the instructor. In the CAI case, the course development costs may be compared with writing a book, with initial development being amortized over the number of students who eventually take the course. Costs decrease nearly linearly until development costs become a small part of the operation (including capital amortization) and maintenance costs of the equipment, at which point costs per student hour become constant. Only system "A" and "C" costs were plotted so as not to complicate the graph unduly. System B would, of course, lie between the other two systems in per hour costs.
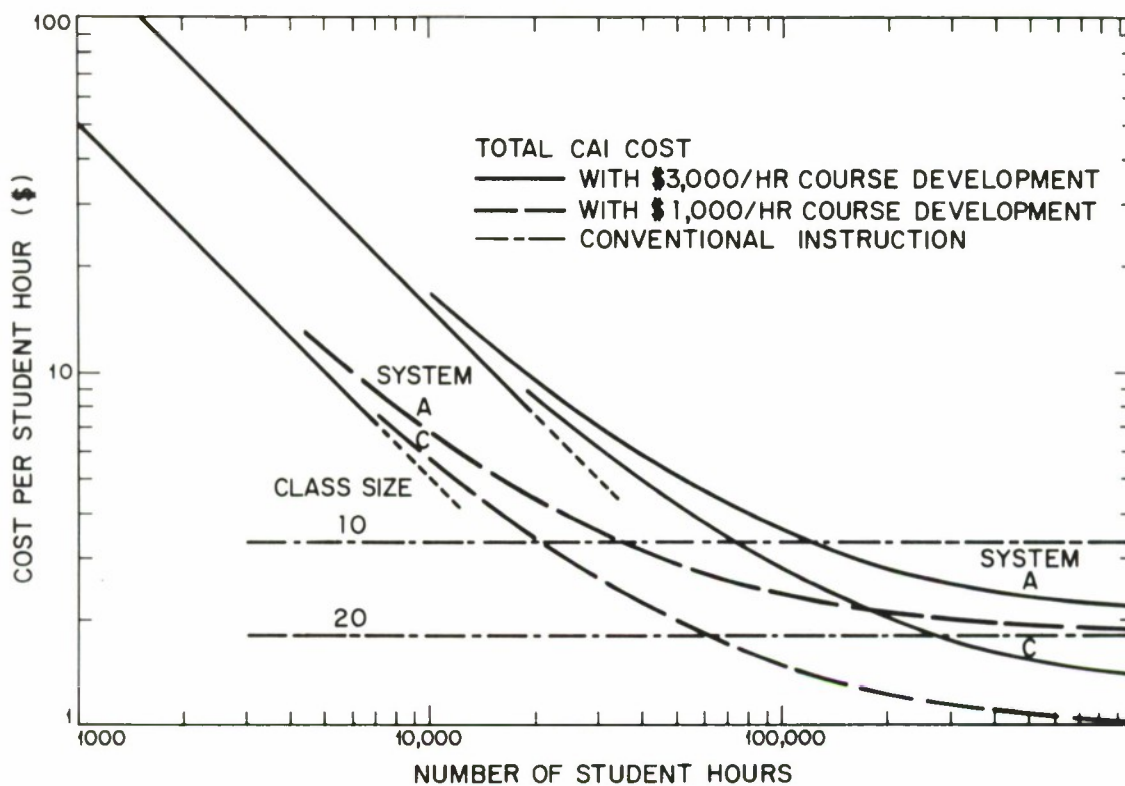
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Fig. 2.   CAI Cost per Student Hour.

For the assumptions made, the CAI costs become competitive with conventional costs when 50,000 to 100,000 hours of instruction are given. This corresponds to 1000 to 2000 students completing the course. Since it is the number of students who use a given unit that is important in amortizing that unit (regardless of its length) it follows that the 1000-2000 student number holds for any length course.

It is interesting to speculate on how increased experience with CAI may affect the costs of that medium and the resulting change in the cost crossover point between CAI and conventional instruction. One can expect manpower costs to increase with time, and since preparation for conventional classes or for CAI are highly manpower intensive, one would anticipate that the preparation costs for the two media will rise together. CAI hardware costs can be expected to decrease through increased production and increase somewhat because of inflation. The net change will probably be downward, but for a conventional course of 50 hours, a relatively large decrease in hardware cost will not change the crossover point by a significant amount (because of the high overhead costs). Above the 2000-student point, the cost ratio between conventional and CAI costs will increase rapidly in favor of CAI as hardware and operating costs drop.

Significant changes may take place in Figure 2 when the assumption that one can collect students on a continuous basis into neat classes of 20, or any other number, on a regular schedule does not hold. In conventional training, one then has instructors employed inefficiently. With CAI, one has terminals used inefficiently. In either case, the geographic dispersion of students may affect the cost. When students are so dispersed that classes as large as 10 cannot be assembled, CAI becomes

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economically attractive for a lesser number of student hours, provided that hardware operating costs do not increase with decreasing size of student clusters and provided that the total student body is large enough to amortize courseware costs. With conventional training, students must be brought to a central location, thus incurring travel and subsistence costs; with all but stand-alone CAI, communication costs are incurred if the students are to be training in isolation. Air fare costs, currently of the order of 10¢ per round trip mile, are less than anticipated data line costs, but subsistence costs -- say $25 per day -- will be well above anticipated data line costs for nominal distances.

ESD-TR-75-150

ERRATA SHEET

for

TECHNICAL NOTE 1975-23

Author R. C. Butman overlooked incorporating the following changes in the section on Utilization Efficiency in his discussion of "Computer Assisted Instruction; Some Techno-Economic Factors," 1 April 1975:

Page 19   Definition of C should read:

cost of central computer per hour

Page 20   For LTS^4

$(m = N = \alpha = 1)$

UTILIZATION EFFICIENCY

CAI costs are usually quoted as those costs per terminal hour which obtain when the maximum possible number of terminals are installed and when all terminals operate 100% of the time scheduled. When either situation does not exist, the resultant lower system utilization efficiency increases the per terminal hour cost.

The utilization efficiency of a CAI system may be expressed as:

$$U = \frac{T + mC/N}{T + mC/\alpha N} \left(\frac{h}{H} \right)$$

where:

T = cost of each terminal per hour plus non-computer overhead (communication lines and terminations for example).

C = cost of central computer per hour per terminal when central computer is operating with design number of terminals (N).

N = maximum number of terminals allowed per central computer.

αN = actual number of terminals installed ($0 < \alpha \leq 1$).

H = scheduled system hours per year.

h = actual system hours per year.

m = number of central computers in use.

This equation acknowledges that a CAI system operated by a central computer, must divide the operating cost of that computer among the number of terminals installed. If the chosen computer can service several thousand terminals, but there is a need for only one thousand terminals, then the computer cost per terminal is higher than the design value. The variation in efficiency of operation as a function of the number of terminals installed is dependent on the ratio of the central computer cost to the terminal cost (C/NT).

The expression is rewritten:

$$U = \frac{1 + mC/NT}{1 + mC/\alpha\ NT}$$

The relationship is examined by normalizing computer cost to a terminal cost equal to one and plotting the resulting function.

It has been determined that:

For LTS[4] $\dfrac{C}{NT}$ = .2; $U = \dfrac{h}{H}$, (m = n = N)

For TICCIT[2] $\dfrac{C}{NT}$ = 3; $U = \dfrac{1+3m}{1+3m/\alpha}\left(\dfrac{h}{H}\right)$

For PLATO[1] $\dfrac{C}{NT}$ = .6; $U = \dfrac{1+.6m}{1+.6m/\alpha}\left(\dfrac{h}{H}\right)$

where $\dfrac{C}{NT}$ = The cost of the central computer when the total cost of the terminals equals 1.

The above assumes that capital costs are a measure of operating costs and that the ratio of capital to operating costs are the same for all hardware elements in the system. A more elegant analysis would attempt to find a better basis for determining operating costs.

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Given these figures, one can generate Figure 3 which shows the system opera-

ting efficiency as a function of the number of terminals purchased and installed. A

maximum terminal utilization of 80 percent is assumed; that is, $\dfrac{h}{H} = 0.8$. This

simply recognizes scheduling problems and equipment down time, in effect asserting

that on the average each terminal is active 80 percent of the scheduled system time,

assumed here to be 2000 hours, per year. This may be an optomistic assumption --

potential users must assess their own environment and determine probable terminal

utilization.

The drop in efficiency in each case occurs when a new computer has to be

added. In practice, the breaks might not occur at precisely the points shown since

the 2000 hours per year per terminal and the 80-percent utilization are not rigid.

However, the drop in efficiency will be to the depth shown when a new central computer

is added without adding terminals. The efficiency figure shown is divided into the

cost per terminal hour specified for full system operation to obtain actual cost per

terminal hour. Thus, with 1000 PLATO terminals purchased and in operation, the

system efficiency is 37 percent and the terminal per hour cost is 2.7 times the full

system cost per terminal hour. TICCIT efficiency is 24 percent with 25 percent of

the terminals operating -- the lower figure vis-à-vis PLATO is a result of higher

percentage cost of the central computer per terminal. Note that these efficiencies

assume 80 percent utilization of all installed terminals; for 50 percent utilization of

installed terminals the 1000-terminal PLATO efficiency becomes $.37 \times \dfrac{50}{80} = .23$ so

cost per terminal is increased by $\dfrac{1}{.23} = 4.3$ times the full system with 100 per-

cent terminal utilization. Figure 4 plots actual cost per terminal hour as a function

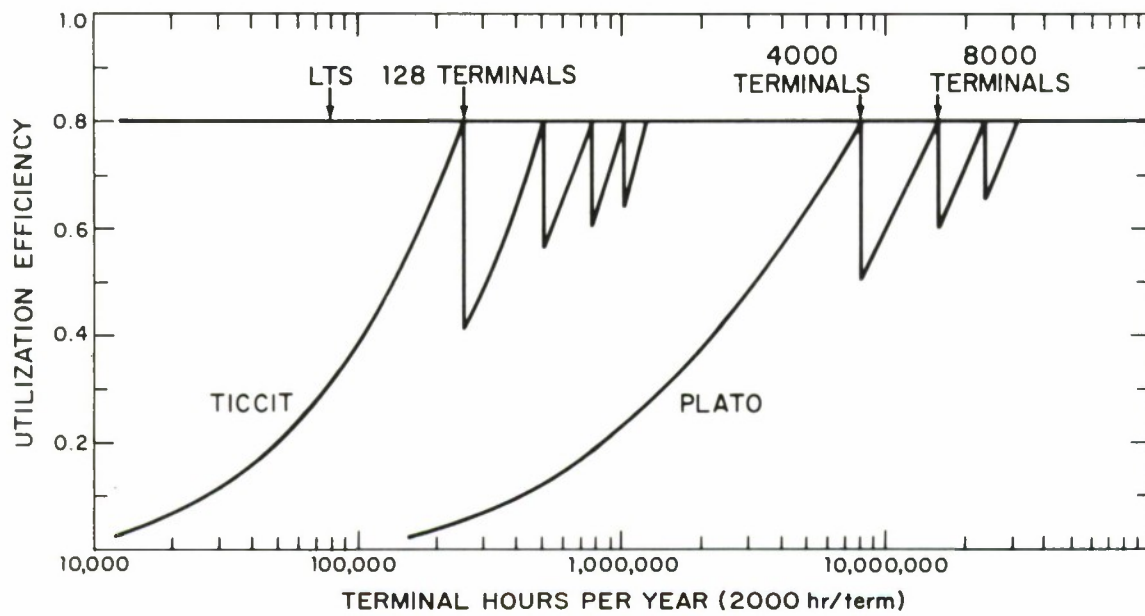of available terminal hours per year.
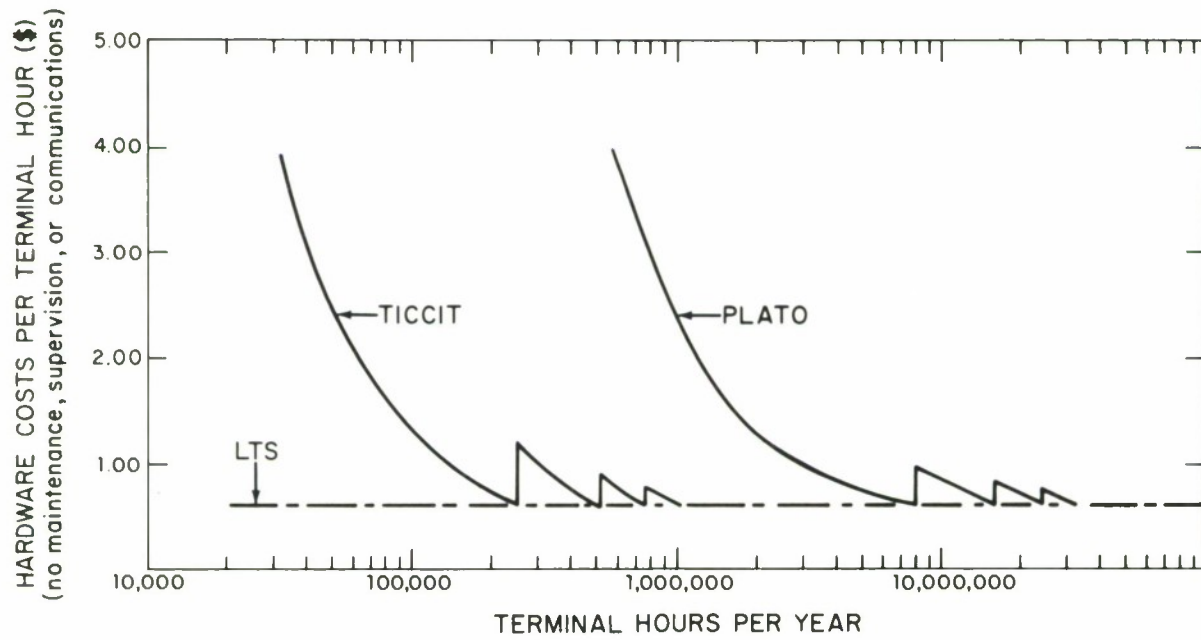
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Fig. 3.   CAI Utilization Efficiency.

Fig. 4.   Basic CAI Hardware Costs per Hour.

SYSTEM CONSIDERATIONS

This section considers the use of CAI in two educational environments, colleges/ universities, and Air Force training. It is beyond the scope of this report to prescribe a specific level of CAI for any of these environments -- the objective is to consider factors governing the use of CAI in a parametric manner so the reader can apply the results developed to his own situation.

University/College CAI

Consider a college student with 15 contact hours per week for two 15-week semesters per year. These 15 hours represent 5 courses, meeting three hours per week. Total contact hours in four years will be 15 x 15 x 2 x 4 = 1800 hours - 450 hours per year.

The first question one asks is, what total student population is required to fully utilize a CAI system as a function of the average percent of student time spent on CAI and as a function of the number of terminals in the system. This is plotted in Figure 5.

As CAI usage per student goes down, the required student body increases. With a 4000-terminal CAI and 10% average use, 140,000 students are required. In such circumstances, one might simply implement fewer than 4000-terminals and live with the resulting increased cost per terminal hour. With a stand-alone terminal, one terminal will serve 5 students at 450 hours/year or 50 at 10% usage (45 hours). As a practical matter, a 1-terminal installation makes little sense, if one expects to make any significant impact on the educational process.
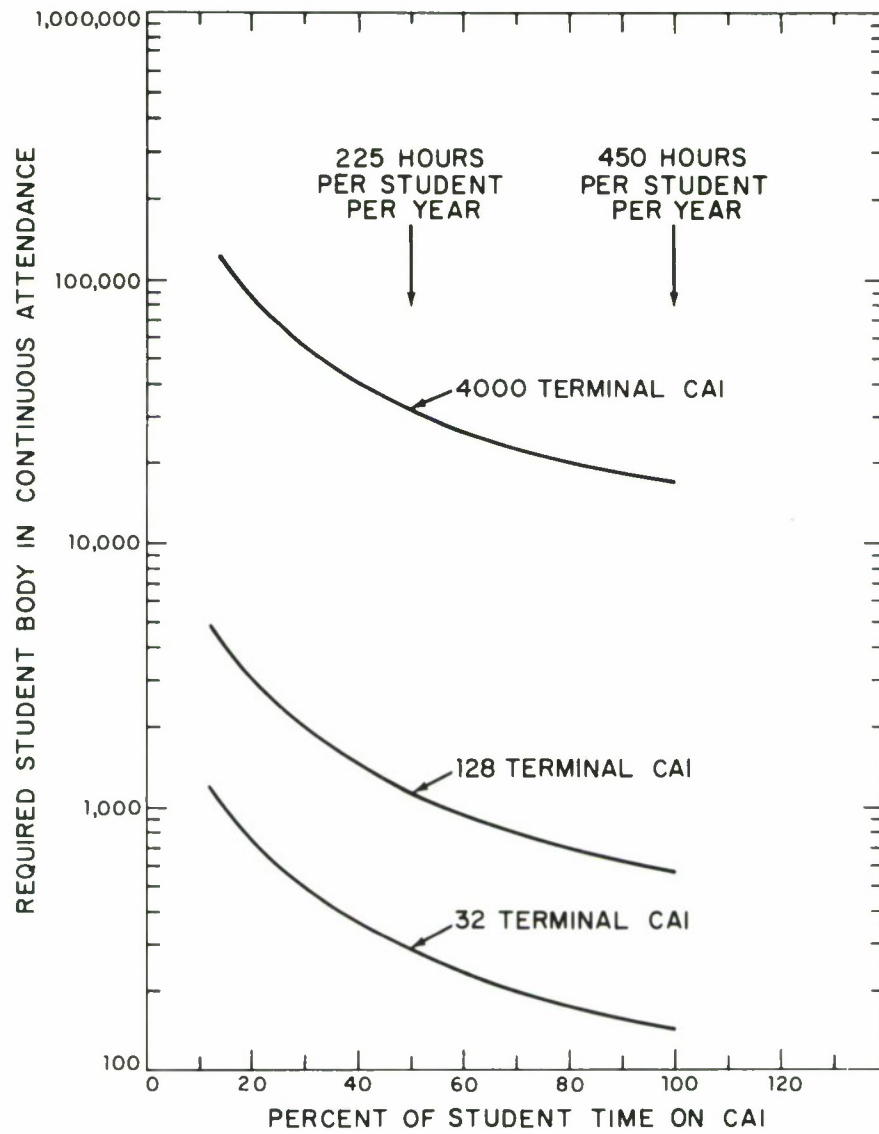
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Fig. 5.   CAI Student Body Requirements.   Civilian case.

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There is a dilemma of sorts in Figure 5 in defining full-time usage. Full-time usage for a student is defined as that time equal to his nominal classroom hours or 450 hours per year. Full-time usage for the CAI system is defined as 2000 hours per year. One may adjust the graph of Figure 5 to suit his own view of what constitutes full-time student use.

In any college, the most likely approach to CAI implementation is to convert high-flow courses first with gradual extension to other areas. Thus, the 10% student use of CAI might, initially at least, mean that the student would be taking 10% of his courses 100% under CAI rather than 100% of his courses 10% under CAI. Whether this approach is cost effective is dependent on the local situation and on the benefits one hopes to obtain through introduction of CAI.

High-flow courses in colleges tend to be courses where class sizes are large. If the objective of introducing CAI is to cut costs by eliminating staff, one must recognize that CAI competes best with courses where conventional class size is small. If high-flow courses have class sizes averaging 50 or so, then it may be that the entire cost of CAI is simply added to the conventional costs, for it is the author's opinion that one supervisor is required to oversee adequately each 50 or so students even under CAI. It must be remembered in this connection, that students under CAI must have access to an instructor when they are in trouble just as a student under conventional instruction. If the objective of CAI is to decrease cost by decreasing learning time, then the school must be so organized that time saved is translated into fewer facilities in use or teachers on the staff. In a period of declining enrollment, this translation may be difficult to realize.

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If CAI is to provide learning experiences for a few students in a subject not otherwise offered at a given campus, then the system must be able to operate efficiently with only a few terminals and the school administration must join with other administrations having similar needs in courseware development in order that courseware will be amortized over an adequate number of students.

Finally, in this discussion, one must consider how many CAI hours per year need to be offered before the system becomes viable. Obviously, the more unique course hours offered, the more terminal hours per year must be used in order to provide for amortization of courseware over a reasonable period of time. Figure 6 is a parametric presentation of the situaton.

The figure plots unique course hours, that is, how many hours of courseware are in storage -- which one can afford to develop as a function of the number of terminals in use. The figure is simply a plot of the equation:

$$\text{Unique Course Hours} = \frac{\text{Number of terminal hours in chosen amortization period}}{\text{Chosen courseware amortization time in hours}}$$

If the cost of an hour of courseware can be amortized to the school administration's satisfaction with 2000 uses (2000 hours) in one year and the CAI system has 1000 terminals each operating 2400 hours per year, and all courseware is equally likely to be used, then one can afford to develop:

$$\text{Unique Course Hours} = \frac{1000 \text{ terminals x } 2400}{2000 \text{ hours}} = 1200$$
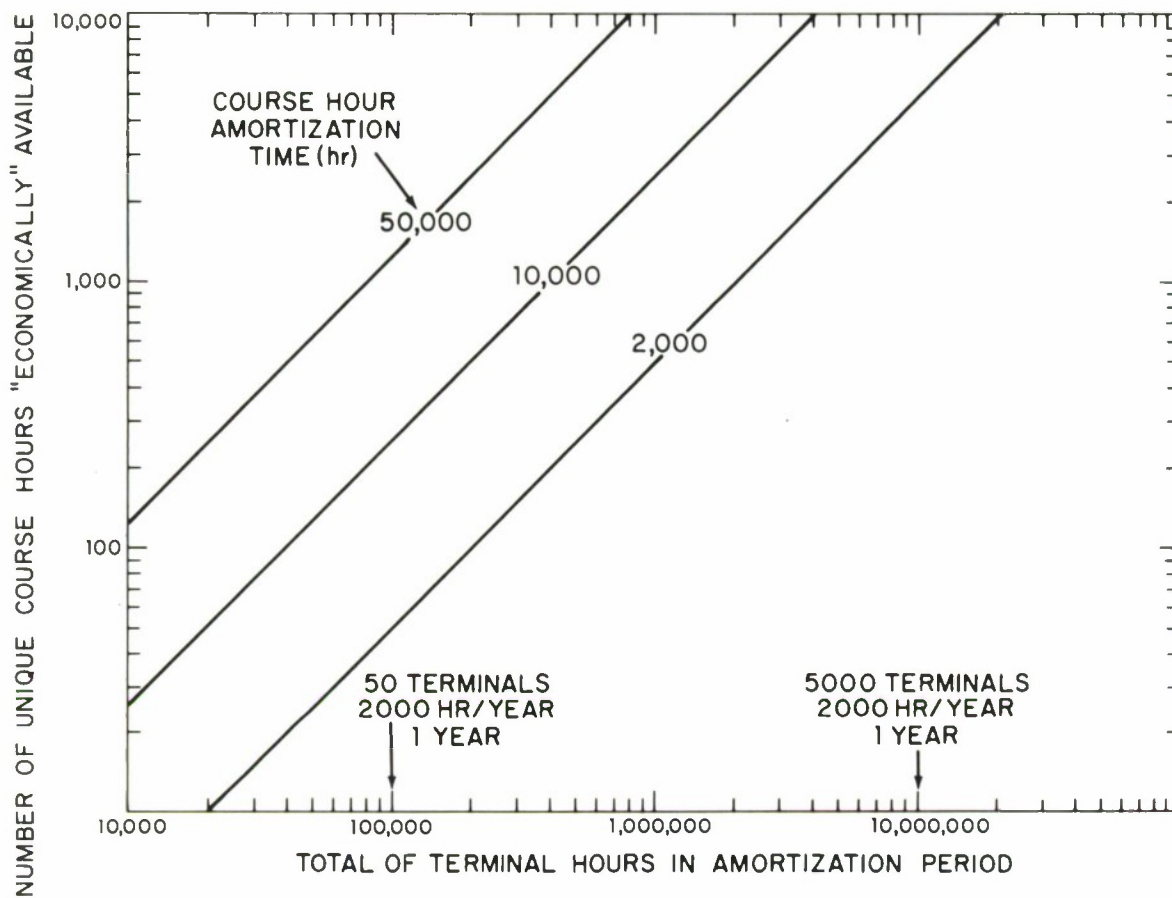
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Fig. 6.   Unique Course Hours   Economically Available.

In the real world, not all courseware will be accessed with equal frequency and the chosen amortization period or use requirement will vary in accordance with initial development cost and the probable courseware lifetime. This means that the decision with respect to the size of the courseware development effort must recognize these differences.

Air Force Use of CAI

Two major categories of Air Force training will be considered in this section; these are Air Training Command Schools and Career Development courses. These two environments are vastly different. The Training Command is concerned with the operation of schools with thousands of students in daily attendance. Career development courses (CDC) are available to Air Force personnel everywhere, and the numbers who are studying a given course on any given base are small.

Training Command Bases

The economics of CAI installations at Training Command bases is concerned largely with the problems and costs of interbase communications which may be required for large system use. For ATC bases, where student populations are large, only CAI systems with thousands of terminals (PLATO) could use interbase communications. Other systems where the central computer serves of the order of 100 students would have one or more installations on each base with no usage problem given a rational courseware development program.

The PLATO situation can be examined with the aid of Figure 4 which plots cost per terminal hour as a function of the number of terminals purchased and installed.

The graph is used to determine the hardware cost per hour for the three capital costs of $2000, $5000, and $10,000 for terminals when different numbers of terminals are serviced. The cost per hour figures obtained from the graph are reduced by 1600/2400 from the per hour figures of $0.20, $0.50, and $1.00 shown on page 11, since in military service a 3000-hour schedule and a 2400-hour utilization is anticipated instead of 2000 and 1600, respectively, in civilian service.

Full Implementation (4000 terminals) hardware Cost Per Hour	Difference	3000 term-inals	Difference	2000 term-inals	Difference	1000 term-inals	Difference	500 term-inals
.13	.06	.19	.04	.23	.13	.36	.21	.57
.33	.14	.47	.12	.54	.31	.90	.55	1.45
.67	.28	.95	.22	1.15	.65	1.80	.90	2.90

Assume now that one predicts a use for n terminals at a given base for a per terminal cost per hour of x dollars. Is it worth running data lines to another base to pick up m more terminals, or should one install another computer at the second base to service the m terminals. For example, if a base installation with 1000 terminals is contemplated, under what circumstances would one run data lines to a second base to pick up another 1000 terminals and under what circumstances would one install a second computer at the second base?

For this example, the $5000 terminal is chosen, so for two, 1000 terminal installations each with its own computer, cost per hour per terminal is estimated to be $.90. This allows for no communications charges, though there will surely be some intrabase communication expense.

For a 2000-terminal installation, 1000-terminals at one base, 1000 at another, the base cost per terminal hour is $0.54 or an average cost per terminal of $0.36 below the 1000-terminal case. This implies that the break even point (2 computers or 1) occurs when the communications costs to the remote 1000-terminal is $0.36 x 2 = $0.72 per terminal per hour for those remote terminals. The factor of two in this case arises of course from the fact that all of the reduced cost attributable to the greater computer utilization can be applied to the data line cost to the 1000 remote terminals.

AT & T rates for 1200 bps data line* required for each terminal is estimated to be $0.50 per mile per month. Data set costs are estimated to be $65 per line per month. Total monthly cost per terminal is then $65.00 + .50 d$ where d is the interbase distance in miles. Hourly communications cost based on 2400 hours use per year (200 hours per month) is:

$$\frac{65.00 + .50 \text{ d}}{200} = .33 + .0025\text{d}$$

For this to equal $0.72 per terminal, the break even cost, .0025d must equal $0.39 corresponding to a distance of 155 miles. So for the example chosen, it would be more economical to install a second computer where the interbase distance exceeds 155 miles rather than to run data lines.

Using the same reasoning, assume a 2000-terminal installation. Shall a second 1000-terminal base be equipped with a second computer?

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* Some PLATO terminals are now reported to be operating with 300 bps data rates. If this rate proves satisfactory in large scale use, line costs will be reduced accordingly.

The basic hardware cost for a 3000-terminal installation is $0.47, the 2000-terminal installation is $0.54, and the 1000-terminal installation is $0.90. For two separate installations, the average cost is:

$$\frac{\$0.90 \times 1000 + .54 \times 2000}{3000} = \$0.66$$

For a single computer with base inter-connections, the cost is $0.47, so the difference available for communications is $0.66 - 0.47 = $0.19 for each of the 3000 terminals or .19 x 3 = $0.57 for the remote units. This leads to a maximum interbase distance of 96 miles. Other examples may be calculated in a similar manner.

The author recognizes that there are wide differences of opinion as to the cost of data lines and terminal equipment. The costs quoted here were obtained from AT & T for estimation purposes only. The objective is to illustrate the problems involved with multi-base operations. If consideration is to be given to a specific installation, documented line costs can be obtained and used as a basis for determining an optimum system arrangement.

Consideration must also be given to the actual amount of CAI time needed at any given base and the same reasoning, with respect to the size of the student body required to support a given CAI system in a university setting must be used here. The difference is that the number of contact hours per week in Air Force training is closer to 30 hours per week than the 15 considered to be full-time in a University. The graph of Figure 5 is re-drawn as Figure 7 to reflect this difference and the fact that the Air Force year is not 30 weeks but more nearly 48 weeks, so total contact hours

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chosen to be 100% of students available time is 1440 hours. With 25% (360 hours) CAI time per full year equivalent student, a continuously present study body of 33,000 is required to fully utilize a 4000-terminal CAI and 1100 to fully utilize a 128-terminal CAI. If the average course length is about 15 weeks, then the student flow per year is 3 x 33,000 = 99,000 students or 3300 for the two examples. Total scheduled time per terminal is 3000 hours per year reflecting the intense use expected in the Air Force environment.

With the foregoing in mind, the population of several large ATC bases are tabulated along with an estimate of the student population and the number of terminals required to support these students under CAI for 288 hours per year (20% of 1440).

	Military	Civilian	Estimated No. of Students	No. of Terminals Required to Support Students 288 hrs/yr*
Chanute	10231	1874	8300	1000
Keesler	15354	2795	12500	1500
Lackland	24412	2444	18500	2200
Lowry	10361	1626	8200	990
Offutt	10935	1843	8800	1050
Sheppard	14444	2362	11200	1350

The Table assumes that the CAI system can operate 3000 hours per year (a higher figure is chosen for military use than civilian use) and that terminal scheduling problems result in actual per terminal use of 2400 hours per year. The 288 hours chosen for CAI time is not a recommended figure but it is realistic.
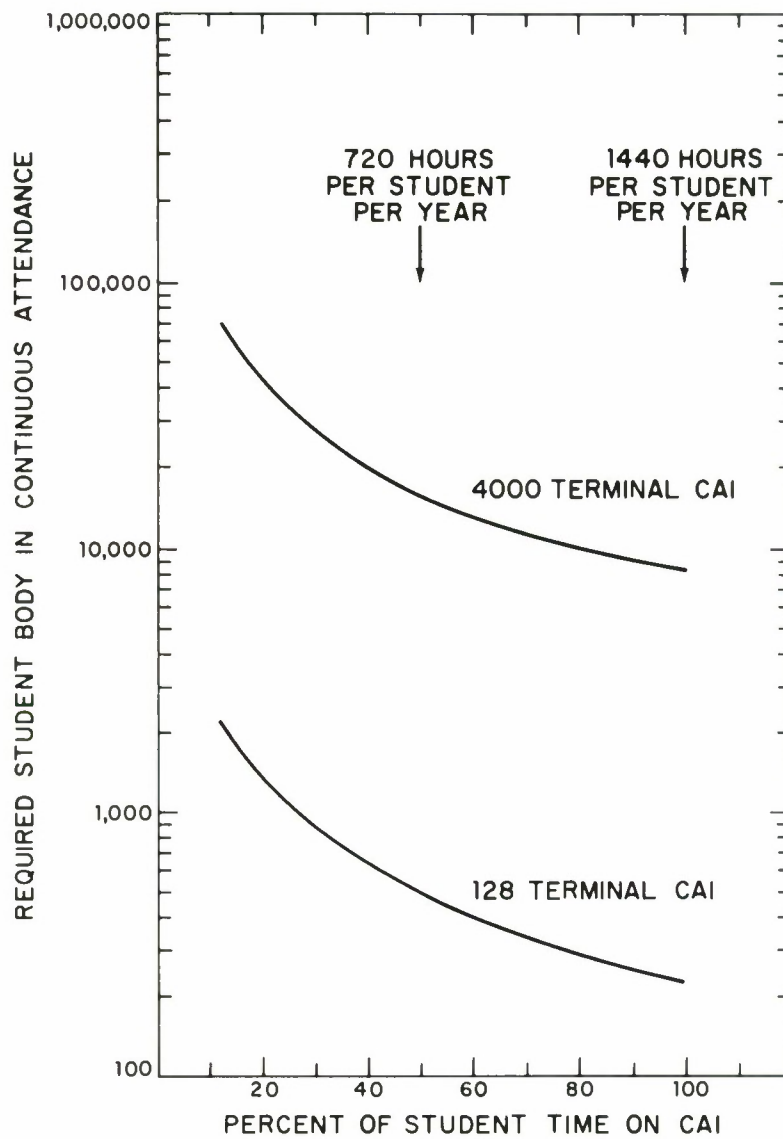
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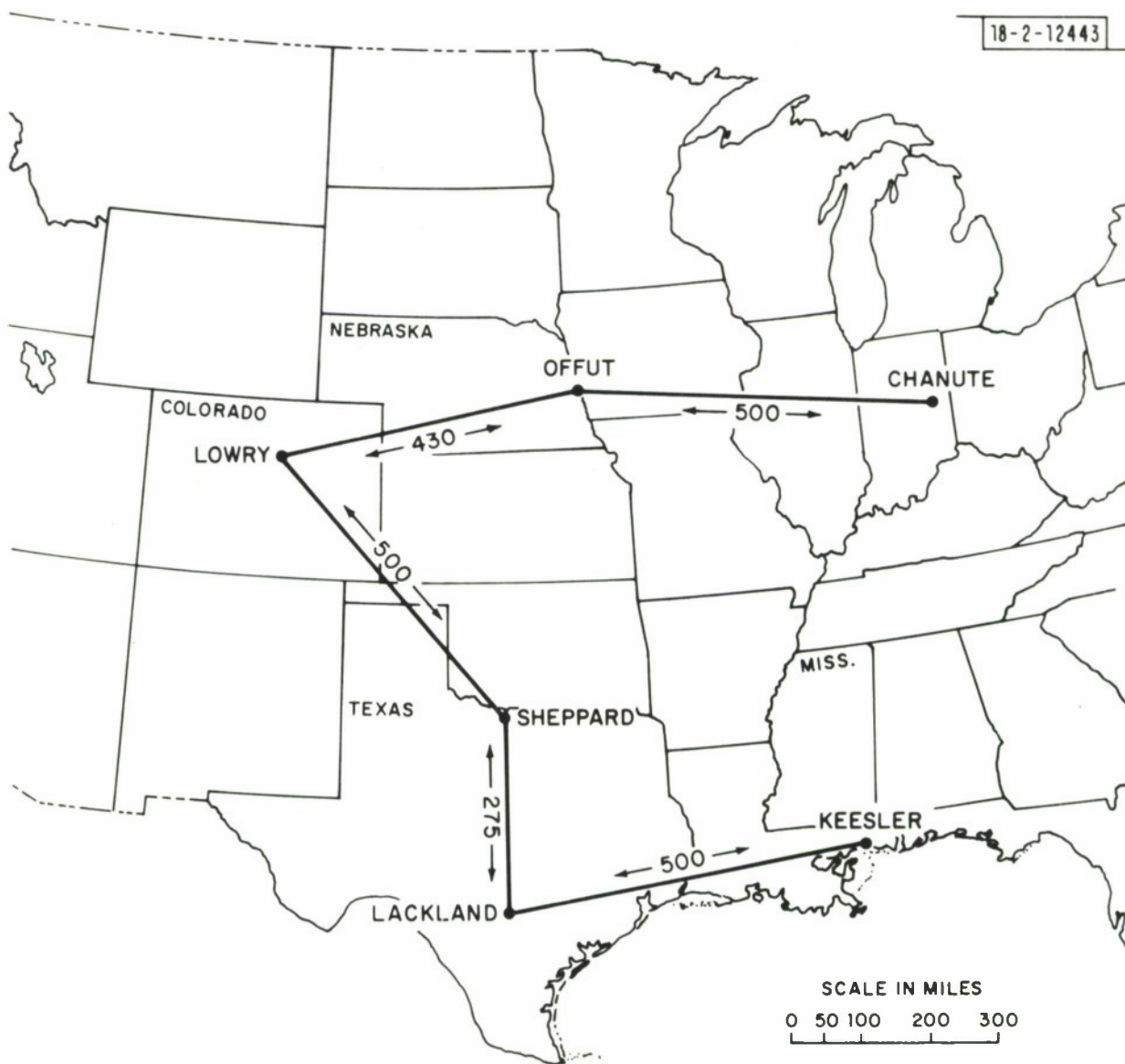Fig. 7. CAI Student Body Requirements. Armed Services Case.

Fig. 8. Air Training Command Base Locations.

The distances between the bases in the table are shown in the map; Figure 8. The distances average almost 500 miles so that at 50¢ per mile line charges, exclusive of terminations would be of the order of $250 per terminal per month or $1.25 per terminal hour. With termination charges of $65/month, per hour costs for interconnection become $1.58 per hour. This results in a terminal per hour cost of $2.03 even for a fully utilized computer. One concludes that with interbase distances of 500 miles, it is more economical to operate independent computers for a number of terminals per computer as low as 400, for at that figure per hour costs become $1.90.

Average cost per hour for single base installations, assuming a per terminal fully implemented system cost for hardware only of $0.50 per hour are tabulated below for all three systems:

	terminals	TICCIT*	PLATO*	LTS*
Chanute	1000	.45	.85	.45
Keesler	1500	.45	.65	.45
Lackland	2200	.45	.50	.45
Lowry	1000	.45	.85	.45
Offutt	1050	.45	.85	.45
Sheppard	1350	.45	.70	.45

* Assume per terminal cost, exclusive of communications equal to $5000. Cost figures taken from Figure 4 and multiplied by $\frac{1600}{2400}$ to account for the increase in usage predicted for military use. TICCIT cost per hour will fluctuate some above $.45 but the number of terminals is large enough so that round off problems should be relatively small.

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With lower demand than that which is stated, PLATO costs increase while LTS remains constant and TICCIT essentially constant. However, as noted earlier, there is no incentive for sharing a PLATO computer between bases so long as distances are of the order of 500 miles and data line costs are as stated.

In summary, one can say that the high-flow ATC bases are poor candidates for computer sharing because of the apparent high cost of interconnection.

Career Development Courses

The number of airmen enrolled in career development courses at any given base is much smaller than those in formal schools. The ten Air Force bases having the greatest enrollment in CDC's on April 28, 1974 were as follows:

Base	Enrollment	CAI Terminals required* to support three hours per week per student (48 weeks per year)
Travis	1221	122
Minot	1062	106
Davis-Monthan	978	98
Langley	975	97
Little Rock	969	97
Offutt	963	96
Eglin	962	96
Nellis	887	89
Barksdale	830	83
Grand Forks	813	81

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* 75% terminal utilization (slightly lower than in regular school use because scheduling is more difficult).

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The demand implied here could be satisfied by LTS, or by TICCIT if one accepts a modest increase in cost over the fully implemented TICCIT. With nominal communication charges, there is no way that enough CDC students could be accumulated to fully utilize a PLATO system for the distances involved would be too great. One might consider the possibility for a PLATO system installed at a major ATC base serving CDC students at nearby bases. Ninety-six lines could be run from Keesler to Eglin for example, but that is approximately 180 miles so line costs would be $.33 + .0025 \times 180 = \$0.78$ per hour based on a 2400-hour year. This is a tremendous overhead burden to place on a system.

One is led to conclude that there is no economical way to supply CAI for CDC's by netting bases together.

PROGRAMMED MATERIALS

A comprehensive economic study of training techniques should, of course, include an analysis of various audio visual aids, programmed texts, and curriculum streamlining, and OJT versus formal schooling. Such an analysis is beyond the scope of this paper. However, since comparisons between CAI and programmed texts have been made, a few comments on that comparison are in order.

It has been suggested that programmed learning booklets can be as effective as CAI provided that the effort expended on material development is equivalent to that spent on CAI courseware development. Results of an experiment which tend to support this thesis were reported in a 1973 Air Force Report[5]. The report describes the use of programmed materials derived from CAI courseware originally developed for use on LTS.

The cost of developing and using such material relative to CAI is of interest.

It is estimated that the development cost of programmed text preparation may be of the order of 1/2 to 2/3 of the cost of CAI preparation (the lesson objectives) must be established, the mastery tests written, all of the visual frames must be generated, the programming developed and the resulting material printed). It was noted previously and should be re-emphasized here that in the military, course development costs may in fact be quite insensitive to the delivery medium used. This simply reflects the large effort expended in defining course objectives and in developing specialized material.

It is assumed that student-instructor ratios will not change with the intro-duction of programmed materials, although it may well be that the individualized attention required when students are progressing at their own speed will, in fact, lead to reduced student-instructor ratios. Programmed texts, if they are to decrease learning time, must permit students to move at their own pace. This means that the instructor must cope with students at all points in a lesson. All instruction and remediation is, therefore, individualized and time consuming. For a class of 20 students, instructor cost is estimated at $1.50 per student hour and twice that for a class of 10. The cost of using programmed instruction under these circumstances would be as shown in Figure 9. Preparation of materials is assumed to cost $1500 per hour. Programmed instruction cost under small class conditions (10) levels off at a higher cost than the most expensive CAI and with large classes (20) is higher than the lowest cost CAI considered. This comparison is, of course, sensitive to the number of staff required to manage students operating under CAI. Experiments indicate that the 40/1 ratio chosen is adequate.[6]
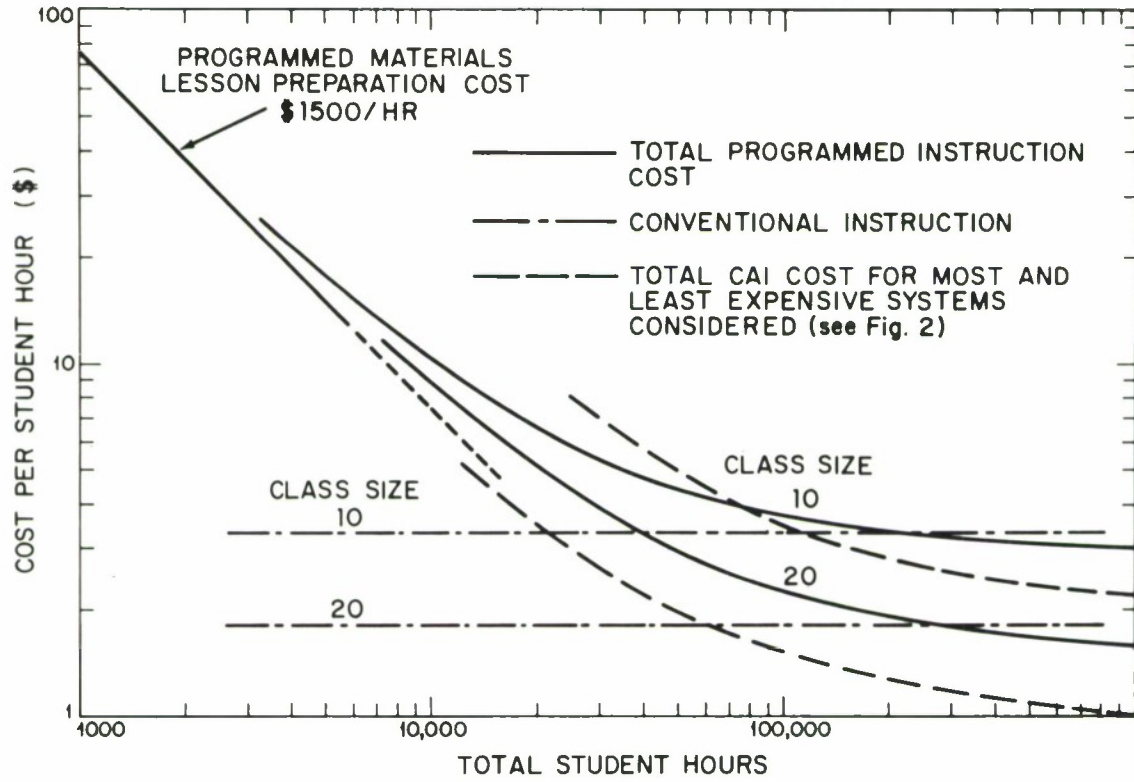
Fig. 9.   Programmed Instruction Costs.

CAI AND INSTRUCTOR REQUIREMENTS

CAI will change the modus operandi of the instructor. The instructor's role will be to interact with students who are having difficulty in mastering a skill or concept on his own (with CAI guidance). Experience indicates that this time is less than one percent -- which would equate to a student instructor ratio of 100 if no queuing problems existed. [6]

In actual practice, it is estimated that each instructor could accommodate 40 students. In addition, one maintenance man would be required for each 40-50 machines so the active staff required under CAI is approximately 20/1.

Total staff utilization is affected by the student flow rates and by the uniformity of that flow. Classes in basic electronics, large in size and predictable in starting dates can in principle use instructors efficiently. Efficient instructor utilization is more difficult with small courses. One example of this, drawn from Air Force experience may be found at Keesler Air Force Base. Of 290 courses offered by the Keesler Technical Training Center, 200 have a flow of fewer than 50 students per year.

This low flow coupled with scheduling problems makes instructor utilization inefficient. One is led to consider CAI as a mechanism to improve instructor efficiency. The theory is that although flow rates for a given course may fluctuate significantly, the fluctuations for all small courses offered will be less violent. That is to say that the total school population fluctuates less than the population of any given small course. This means that CAI terminals could be used efficiently, whereas instructors -- who are specialists and so confined to teaching one or two courses -- cannot.

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A clear conclusion on this cannot be reached without a detailed examination of the actual situation. One of the factors which must be considered is, of course, the total number of students who will eventually take any given course. If the flow is 50 students per year, then 20 years will pass before 1000 uses are made of any given hour of CAI instruction. If preparation costs are $3000 per hour, then amortized over 1000 uses, those costs are still $3/hour. This will be acceptable only if current instructor costs are well in excess of that figure. In this connection, it must be recognized that there must always be a minimum of one qualified instructor for each course, no matter how much CAI is involved, to act as a consultant to students who are in trouble.

In general, wherever CAI is used, one expects to save on high-flow courses by saving time and instructors. On low-flow courses, one can realize the same savings, though in practice the instructor saving may be higher because of current instructor utilization inefficiencies resulting from the irregular flow and small size of the student body. The question is whether or not total flow over several years is large enough to justify the cost of CAI or programmed instruction preparation costs. Note that in this case, hardware costs are spread over many small courses so these costs are no more limiting for small courses than for large ones so long as there are many small courses being offered.

Instructor training for CAI is not a major problem. The instructor must be able to respond to questions about widely differing parts of a course -- a skill that may not be required in the conventional classroom. Other than that, no special skills are needed.

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CONCLUSIONS

The argument that it is possible to save money (avoid costs) with the aid of CAI is a valid argument. One cannot say, however, that CAI will help avoid costs in all training situations. CAI will be of value in courses where high flow rates lead to amortization of courseware preparation costs at a sufficiently rapid rate so that changing training requirements do not lead to a high courseware update cost. CAI, by supporting training outside of conventional school environment, can increase the efficiency of OJT -- accelerating upward and/or lateral transitions of trainees.

It is important to recognize that one of the salient virtues of CAI is its inherent ability to support learning in any environment. It is crucial, therefore, that this virtue not be sacrificed through poor engineering design.

Applications areas for CAI must be chosen with care. Flow rates, value of student's time, learning, environment, probable pre and post CAI student/instructor ratios, dispersion of the student body, course lifetime, etc., must all be taken into account if a rational application decision is to be made.

The large investment required to implement a CAI system leads to a conclusion that successful introduction of CAI will only be accomplished by administrative fiat. The initiating organization must be large enough to develop the large flow of students required to make CAI economically attractive or it must have the coercive power to get other organizations to become involved in a joint program.

A decision to use CAI must be based on an analysis of costs and benefits as viewed by top level management. Local levels tend to be plagued with parochial views --

instructor costs are "given" and alternative organizational approaches are not visible. There are few if any instances where technology has been cost effective on a small scale. There is no reason to believe that training and education are unique in this regard.

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ESD-TR-75-150	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Computer Assisted Instruction; Some Techno-Economic Factors		5. TYPE OF REPORT & PERIOD COVEREO Technical Note
		6. PERFORMING ORG. REPORT NUMBER Technical Note 1975-23
7. AUTHOR(s) Butman, Robert C.		8. CONTRACT OR GRANT NUMBER(s) F19628-73-C-0002
9. PERFORMING ORGANIZATION NAME ANO AOORESS Lincoln Laboratory, M.I.T. P.O. Box 73 Lexington, MA 02173		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Project No. 649L
11. CONTROLLING OFFICE NAME AND ADORESS Air Force Systems Command, USAF Andrews AFB Washington, DC 20331		12. REPORT DATE 1 April 1975
		13. NUMBER OF PAGES 52
14. MONITORING AGENCY NAME & AOORESS (if different from Controlling Office) Electronic Systems Division Hanscom AFB Bedford, MA 01731		15. SECURITY CLASS. (of this report) Unclassified
		15a. OECLASSIFICATION OOWNGRAOING SCHEOULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. OISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

None

19. KEY WOROS (Continue on reverse side if necessary and identify by block number)

computer assisted instruction systems   educational technology program   training techniques

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Successful implementation and use of any CAI system requires that careful attention be given to the costs and benefits of CAI in the chosen environment. This paper considers costs as a function of system utilization factors and size and geographic dispersion of the student population. Comparisons are made between three generic CAI systems — a system with several thousand terminals, a system with 128 terminals and a system where the computer is integral with each terminal.