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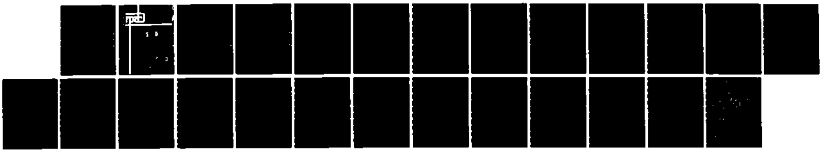

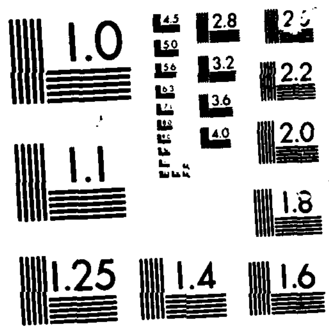

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NPRDC SR 79-18

APRIL 1979

THE QUEST FOR AN INEXPENSIVE, GENERAL-PURPOSE, STAND-ALONE COMPUTER

NPRDC Special Report 79-18 April 1979

THE QUEST FOR AN INEXPENSIVE, GENERAL-PURPOSE, STAND-ALONE COMPUTER

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FOREWORD

This study addresses a number of issues involved in the design and selection of inexpensive, stand-alone computing systems. It is based on material provided by Kenneth L. Bowles, Institute for Information Systems, University of California, San Diego, under contract N00123-76-C-1546, and should be of interest to organizations considering distributed, computer-based instructional applications.

This work was conducted in response to Advanced Development project ZPN08, Education and Training Development, Subproject Z0108-PN.32 (Advanced Computer-Based Systems for Instructional Dialogues), under the sponsorship of the Chief of Naval Operations (OP-99). Drs. J. D. Fletcher and J. D. Hollan served as technical monitors.

DONALD F. PARKER
Commanding Officer

SUMMARY

Problem

Recent investigations of computer-based instruction have shown that such technology has a number of benefits for Navy training. Unfortunately, current systems require large, timeshared computers, making it difficult to deliver instruction at many distributed sites such as at dockside or aboard ship.

Purpose

The objectives of this research were (1) to evaluate the issues involved in the design and selection of portable, inexpensive microcomputer systems powerful enough for interactive instructional applications, and (2) to set forth specifications for such a system for Navy use.

Approach

Various issues involved in the design and selection of portable, inexpensive computing systems were studied, and specifications for such a system for Navy use were derived from the findings of that study.

Results

1. A portable system of sufficient power to provide interactive instruction is currently available for about $5500.

2. Software and hardware specifications for a microcomputer system are provided. The software is designed to be transportable to more powerful microcomputers as they become available.

Conclusions

Portable, inexpensive, microprocessor-based computing systems currently are capable of delivering interactive instruction. There is every indication that the computing power of such systems will continue to grow, while their cost will probably continue to decline. Therefore, they should be considered as a means of providing stand-alone, computer-based instruction at distributed sites.

Recommendations

The use of microcomputer systems for instruction should be tested on critical Navy training problems where distributed (i.e., nonschool) training is an important option. Because of rapidly changing microprocessor technology and high software development costs, every effort should be made to make software portable so that it can be transported to less expensive and more powerful systems as they become available.

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INTRODUCTION

Problem

Because of the dispersion of Navy operations, fluctuating environmental conditions, severe space limitations, and equipment nonuniformity, special requirements are placed on Navy training systems. Recent investigations of computer-based instruction have shown that such technology has a number of benefits for Navy training, but current systems require large, timeshared computers, making it difficult to deliver instruction at many distributed sites such as at dockside or aboard ship.

Purpose

The objectives of this research were (1) to evaluate the issues involved in the design and selection of portable, inexpensive microcomputer systems powerful enough for interactive instructional applications, and (2) to set forth specifications for such a system for Navy use.

Background

Trends

Increasingly, small computers are being used as stand-alone processors and intelligent terminals. Quite often, the stand-alone processor can perform a set of tasks at lower cost than is possible with a shared machine, even if the latter is a timeshared minicomputer. The trend is toward "distributed processing," in which (1) increased processing power is vested in terminals of an intercommunicating system, and (2) central machines are relegated to file and retrieval tasks. The trend is a result of microprocessor technology and Large Scale Integrated circuits, which make the distributed arrangement less expensive than the traditional medium, or large shared machines.

Another trend is the change in the relative costs of software and hardware. For many applications, the cost of software has become much larger than the cost of its intended hardware. To the extent that software can be shared, it should be employed on as many small computers as possible so that software development costs per machine can be brought within the range of hardware costs.

Promising New Technologies

The computer industry is innovating fast enough that the specifications for an ideal stand-alone small computer are not expected to remain stable for very long. New technologies promise not only to change how computers are used, but also, in some cases, to allow new computer applications that were not economically practical in the past.

The video disk is one of the most attractive new technologies. Several large companies will soon be selling home television playback units based on disks about the size of a long-playing phonograph record, with a capacity of 30 to 60 minutes of television programming. These disks also could be used for the storage and random retrieval of large amounts of digital information.

The typical capacity of such a disk is more than one billion 8-bit bytes. The video disks are write-once, read-only devices. Generally, copies are made from a master disk that was made on a relatively expensive recording machine. The cost of copying a master disk depends upon the recording method employed. One company has a patented recording method that uses a disk made of ordinary photographic film, and a playback unit employing ordinary white light. The system should prove useful for educational and scientific applications, since copies of a master disk can hold a maximum of 54,000 still TV images, 1.25 billion bytes of digital information, or a mixture of the two. Access time is about 0.1 second.

Distributed processing is a combined hardware/software technology that has become more attractive with the advent of powerful stand-alone computers and reduced costs for fast-access, hard read-write disks. In applications where central file storage is desirable, the most economical design may involve many stand-alone processors operated part-time as intelligent terminals connected to a small machine acting as a file manager and message forwarder. In many cases, the central machine can be a microcomputer similar to the stand-alones connected to it. The central machine would often be required to do very little processing other than what is necessary to pass messages and to index and retrieve information stored in disk files.

ISSUES

Software

Although many users are satisfied to use or teach BASIC as their principal higher-level language, BASIC is awkward for writing large programs and is not well suited to teaching structured programming concepts. An alternative is PASCAL, which has already been used as the basis for a general-purpose interactive system. PASCAL is designed for teaching modern ideas of structured programming as required by many employers, and it can be used to implement efficient, large-scale software. In addition, it can support complex interactive programs, such as the CRT-oriented text editor, and programs for computer-based instruction.

One problem with low-cost, stand-alone computers is the high cost of software. For example, the RT11 operating system plus single-user BASIC from Digital Equipment Corporation costs at least $1750 per machine. The cost of each additional language, such as FORTRAN, is about $800. Some system software is in the public domain; that is, can be used by educational institutions without charge. The UNIX operating system from Bell Laboratories is widely used on timeshared PDP-11 minicomputers, and a version of UNIX for small PDP-11s reportedly is available. However, it is also reported that this small-machine UNIX consumes nearly half the memory available on the smallest PDP-11s, creating a space problem for some large user programs.

According to Wagner,[1] software related principles should govern the choice of small stand-alone computers by the Navy and other large organizations. First, the stand-alone should be available with a wide choice of predominant programming languages. The approach taken by Tektronix and Wangco has been to supply just one language processor (usually BASIC or APL) hard wired into the machine. An optional second language processor is available with the IBM stand-alone. Users are not usually given software on removable media because such freedom can lead to larger costs for user support services than the pricing of the units can warrant.

The second general software principle is that machine-independent operating systems and language processors should be in wider use. The concept of standardized programming languages has proven practical only in the case of COBOL, and then only because of a major committee effort and a commitment by the federal government to keep COBOL standardized. The price of such standardization is a long delay in the introduction of new and desirable features. For COBOL, the delay has exceeded the life of most small computers being produced. One problem impeding language standardization has been the difference among large machines in basic attributes such as word size. This has led manufacturers to introduce proprietary "enhancements" with the hope of gaining a competitive advantage. As a result, a program written in FORTRAN on one machine may not run on another unless the programmer has avoided any but the most widely used FORTRAN constructs, and has avoided constructs that work differently on different machines.

Fortunately, the industry has largely standardized on 8-bit bytes, 16-bit words, and the ASCII coding conventions for most mini- or microcomputers now being built. For many applications, low-cost mini- or microprocessors are

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[1]Wagner, F. V. Is decentralization inevitable. Datamation, 1976, 22, 86-101.

more than fast enough, and the implementation of a standard language becomes an attractive possibility. A stand-alone machine requires a relatively simple operating system, and if such a system is written mainly in a standard higher-level language and runs on an interpreter, then most of the related software can be moved without much trouble from one mini or micro to another. Such a system has been implemented using the PASCAL language for all of the software (operating system, compiler, editor, file manager, utility programs) except the interpreter, which consumes about 5K bytes of main memory. The code executed by the interpreter uses less memory space than the equivalent native code for the host machine. To the extent that speed is important, a small number of built-in supports for the system allow the software enough speed for highly interactive processing. The built-in functions include support for string handling and graphics display. Compile speed is about 1000 lines per minute on the PDP-11/10 and about 650 on the LSI-11, and it should be in the same range of the Z80.

The widespread use of interpretive systems of this type would allow wider sharing of application packages among groups using different mini- or micro-computers. Such use might also encourage manufacturers to introduce small processors designed to handle the interpreted codes efficiently. Such small processors are already in production for interpreted imitation of machines like the Data General NOVA. It would be simple to devise a similar processor to handle the PASCAL interpreter without loss of efficiency.

Specifying Graphics

Many users have questioned the need to pay for a graphics display in a minimum-cost, stand-alone computer. Indeed, some applications, such as commerical word processing, need no graphics. However, virtually all major instructional applications, for the stand-alone computer would benefit if a graphics display of moderate resolution were available in addition to a text display. It is possible to design a combined system, using the current generation of electronics, offering graphics resolution of 240 by 320 points at a cost only a few percent higher than that of a text-only system. Given this possibility, the option of graphics in the basic, low-cost system should be made mandatory to achieve widespread user support.

An automated teaching system (CAI) without graphics is like a classroom without a blackboard or other visual aids. With simulation techniques, one can add the dimensions of time-change and adjustability, which are not available with most of the visual aids used for teaching. Graphic illustrations are often very useful for condensing tables of numbers in administrative applications, and play a major role in science and engineering research.

Word Processing

In addition to teaching, one of the most significant potential applications of the small, stand-alone computer is word processing. For professionals, the most important use of word processing is likely to be in the drafting and re-drafting of manuscripts, reports, proposals, and other long documents that are reviewed by several people before completion. This activity consumes large amounts of time for typists and the professionals they serve.

An increasing variety of special-purpose text editing and word processing systems are now available at prices ranging from $10,000 to $20,000. Often, the equipment is based on a small stand-alone mini- or microcomputer. Usually, the manufacturer makes it difficult or impossible for the user to alter the software, thus avoiding expensive consultations with customers not experienced enough to understand the software. In spite of this limitation, more than half of the price reflects the vendors' costs for a field support and marketing staff. Less expensive word processing systems are generally based on a "line-oriented" text-editing program intended for use with a typewriter for both input and output (printing) functions. The more expensive units are based on a display unit, such as a CRT or plasma panel, and are designed so that the typist can observe the effect of each insertion or deletion almost instantly, without having to wait for a time-consuming printout. According to Datapro Research, the typist using a line-oriented editor is about three times as productive as one working with a conventional office typewriter, while one working with a display-oriented editor is over five times as productive. This average refers to the usual commercial mix of typing tasks, and the advantage of the display-oriented editor for the mix found in instructional environments may be even greater.

There is no fundamental reason why the small, stand-alone computer discussed here should not be used for word processing as well as for a mixture of other tasks. The cost of the stand-alone computer should be about $5000 or less, and one would need access to a Diablo or Qume printer or other suitable output device. Computer terminals based on the Diablo and Qume printers can be bought for under $3000, and a receive-only unit costing considerably less should be sufficient. The principal problem for the user of the stand-alone computer who desires word processing is to acquire suitable software. At present a variety of word processing programs is available for the LSI-11 (and other PDP-11 computers), but not with complete documentation and rules that are simple enough to attract users who are not adept in general-purpose uses of small computers. With the increasing interest in word processing, this situation should change soon as more small stand-alone systems are installed.

User Support

Users of general-purpose, stand-alone computers occasionally need expert assistance in using software or program products, in making repairs or adjustments to the equipment, in purchasing supplementary equipment or programs, and in learning what products are available. Support services are often available from large manufacturers, but the price of those services typically ranges from $30 to $50 per hour plus travel costs. Computer centers at some of the large organizations are being reorganized to provide some support services for users of small computers. Except where subsidies are used to hide the costs of these computer center support services from the end users, the centers must either charge relatively high prices for expert help or offer general assistance at a lower level of expertise.

It may be possible for a group of Navy activities, using the same type of small computer, to assist one another at a relatively low cost via a network of interactive terminals. Such a system, called TELENET, is already being used by educational institutions. TELENET users run up communication charges ranging from $2 to $4 per hour from most large urban areas in the United States.

An electronic alternative to the mail system could be provided by storing messages on the disk file system of a host computer for read-out on other terminals. Such a message exchange could operate at an hourly cost of $3.50 to $7.00, depending upon the volume of usage. (EDUCOM, an educational users consortium, is now using a commercial timesharing computer connected to TELENET for communicating with member institutions at an average hourly cost of about $15.00.)

A network of interactive terminals could provide Navy users with the instant-delivery benefits of the telephone without requiring participants to connect to the service simultaneously. Instant communication is available when desired, and it can easily be used by any number of participants without making special arrangements. When delayed communication is sufficient, as often is the case, it would be possible to minimize communication costs by composing messages in the stand-alone computer before connecting to the network. This would minimize the time the user is connected to the network and the charges for communication would depend primarily on the amount of information transmitted. For example, the cost of transmitting a two-page memo should be about $.050 using the stand-alone computer.

Realistic Instructional Costs

Instructional Computing

The uses of computers for instruction are highly diverse, and include, (1) instruction on computer programming, (2) problem-solving in many fields of science (e.g., natural, behavioral, social), engineering, and human affairs, (3) automated aids to instruction (e.g., CAI, computer management of instruction), (4) information retrieval from data bases, (5) simulation of physical or social systems too complex, expensive, or dangerous to reproduce in the classroom or laboratory, and (6) word processing and communication.

The report of the University of California Taskforce on Academic Computing, which includes a detailed discussion of the uses of computers for instruction, notes that all campuses of the University are asking for sharply increased student access to interactive computing facilities; that is, those in which the student converses with the computer by using a keyboard for input and a screen or teleprinter for output. In interactive facilities, each input message evokes a response from the computer within a few seconds, and response time is a qualitative issue. If the average response time is longer than about 1 second for a very simple service request (e.g., cancel the last character sent from the keyboard, cause one line of input text to be accepted), or longer than about 3 seconds for a service request of moderate complexity, then the user tends to become impatient. Occasionally the user may call for a complex operation, such as the compilation of a program of moderate length or execution of an analysis program, and a longer delay may be tolerated.

Whenever a population of instructional computer users is analyzed statistically, a characteristic distribution is found that has considerable economic significance. A very large majority of the users, typically more than 90 percent, is found to use only small amounts of computing resources individually; these are called "median-scale users" in the remainder of this report. A very small minority, typically less than 3 percent, will be found to use more than half of the available computing time collectively; these are called "above-average users." This distribution applies except where strong sanctions are applied to prevent all but small quantities of use per individual. Even on a small computer with limited resources (if shared by a significant number of instructional users) the same highly skewed distribution tends to apply. To deliver computing services that meet the needs of a diverse population, it is necessary to provide for both user categories.

Specialization

A common observation regarding computer systems is that specialization can bring large cost savings, often expressed by factors of 10. Specialization may take the form of specially designed computer hardware, but it more often involves using a general-purpose computer for a homogeneous set of tasks. To realize cost savings by specialization, it is necessary to consume a large part of the resources of any single computer for very similar tasks. This applies to both large computers and small ones.

The interactive computing facilities needed for median-scale instructional computer users can be provided by maxicomputers, timeshared minicomputers, or even small stand-alone microcomputers used by only one person at a time. Considering only the cost of the hardware involved, and assuming that cost to be amortized over a period of perhaps 5 years, then the hourly cost of interactive use of all three types of computers will be close to the same for median-scale instructional users when they alone consume virtually all of the capacity of one machine. This conclusion presupposes that the electronics used in the computers are of recent manufacture. For the mini- and maxicomputers, the hardware amortization part of the cost is reduced to less than $0.50 per hour only by serving a homogeneous population of users whose computer needs can usually be satisfied by microcomputers. To arrange for this on a maxicomputer may require serving 500 or more interactive users simultaneously; and on a minicomputer, 25 to 50 users. For all three sizes of hardware, the cost per user station is in the neighborhood of $5000. (The equipment seen by one user will be called a "user station" rather than a "terminal" since the computer and terminal are unified into one device in the case of the stand-alone microcomputer.

Of course, very few instructional sites are large enough to support 500 or more interactive terminals for the median-scale level of instructional computing. The PLATO system at the University of Illinois is an example of a maxicomputer used in this way. Costs for running PLATO hardware are quoted well above $0.50 per hour, primarily because of the communication costs associated with remote terminals at distant campuses.

Most computer centers operate maxicomputers for a very diverse population of users, often mixing large tasks and small ones in operation at the same time. The controlling software (operating system) of such a maxi must be adjusted to optimize the overall efficiency of operation rather than catering to any single class of tasks. The result is that the overall efficiency, typically ranging from 20 to 30 percent, is lower than would be possible with a homogeneous workload. The machine specialized to a homogeneous mix of tasks would be more efficient, by a factor probably ranging from 2 to 3. On the other hand, the maxi does make is possible for users requiring large computing resources to get their work done. A central policy issue related to the operation of general-purpose maxis is the question of whether or not the many median-scale users will be required to pay higher-than-optimal prices, in effect subsidizing the computing work of a group of above-average users too small to support the maxi's full budget.

Professional Assistance

Roughly half of the operating cost of the typical computer center is spent on the salaries of administrators, operations staff, user consultants, software maintainers, and others. In general, centers cannot charge separately for these services. Since the average charge per hour for the interactive use of maxicomputers is about $5, the hourly price paid for the supporting staff must be about $2.50.

Professional staff may also be needed to support the operation of a timeshared minicomputer or a group of stand-alone microcomputers. For example, most University of California campuses that operate timeshared minis assign one full-time system programmer to software maintenance. Some centers also employ a full-time consultant to assist instructors and teaching aides using a timeshared minicomputer, but the need to maintain this level of support for all microcomputers used at an instructional site is questionable. The operating software for a stand-alone micro is much simpler than the operating software for a timeshared mini. Moreover, trials of new software in the stand-alone environment have minimal influence on users working with mature software. This should allow greater freedom for student involvement in software maintenance in the case of the micros, while allowing some users to continue using mature software. If the instruction is in some area of computer science, then the opportunity for student involvement in software development and maintenance can be an important part of the learning program.

A conservative estimate of the staff costs in this area might be based on a mini- or microcomputer learning center with 50 user stations. Such a center can be adequately supported by one full-time system programmer and one full-time consultant. Total costs for salaries and benefits should be about $40,000 per year. Each user station can be used about 75 hours per week during the 11 weeks of each academic quarter. Assuming no use during the summer months, the annual use will be about 2500 hours per user station, or 125,000 hours for the entire learning center. For courses taught by faculty experienced in the use of computers, and supported by student teaching aids who are also relatively experienced, it is possible to dispense with this supporting staff. Although there are hidden costs for performance of the same functions by the instructors or students, their salaries would be paid in any event to support their courses, and much of their computer-related work would be needed regardless of whether or not the site provided shared staff assistants.

Hardware Acquisition

A new maxicomputer costs from $1 million to $2 million; a timeshared mini, from $100,000 to $200,000; and a stand-alone microcomputer, from $3000 to $6000. The cost per user station may range from about $3000 for a text-only teleprinter to about $6000 for a high-quality graphic display. (Quantity discounts are assumed in these estimates.)

For most sites, the financial commitment to the maxi will imply a program commitment to steer as much computing work as possible to the maxi, even when cheaper or more powerful alternatives become available. However, the rapid advance of computing technology is expected to continue for longer than the expected life of any of the maxicomputers being sold today. To make it feasible to finance the maxi, the organization may have to assume a useful machine life ranging from 7 to 10 years, thus ensuring obsolesence and unhappy users near the end of that life span.

The prices of small mini- and microcomputers are expected to continue to decline over the next 10 years. A typical micro that costs about $5000 today will probably cost no more than $2500 by 1982, and no more than $1000 by 1987. Since most instructional centers currently offer less interactive computing service to students than is needed, a growth in the number of available user stations should be planned from year to year. This means that the average hourly cost for operating the hardware should be based on the expected acquisition cost per user station circa 1980 for the microcomputer approach. A center large enough to project its growth to many of the minicomputer timesharing systems might also calculate hourly costs based on the expected decline in hardware costs. However, it is not reasonable to assume that the same benefits will be available for new maxicomputers because of the long accounting periods needed to amortize the cost of such machines. It should also be noted that interest charges associated with a 7- to 10-year commitment can raise the hardware cost of a maxi by 50 to 100 percent.

It is relatively simple to calculate the average hourly hardware acquisition cost for a micro- or minicomputer to be used for specialized services to the median-level population of instructional users. A similar calculation for a maxi serving a general-purpose mix *is not attempted* here because too many assumptions have to be made about operating policies. To be conservative, it is assumed that a user station costing $5000 will have a service life of 5 years. The quality of the equipment now being sold at that price is such that 5 years is probably a gross underestimate. The annual cost of $1000, spread over an annual utilization, of say, 2500 hours, yields an average hourly cost of $0.40. Maintenance and operating costs then have to be added to obtain the net total cost of use.

Often, the maxi in the computer center is operated as an independent cost center for accounting purposes, and computer terminals acquired for instructional purposes must be bought on a separate budget. Where this is true, a realistic estimate of the hourly cost for interactive instructional computing should include both computer center charges and the hourly equivalent cost of the terminal. In today's market, a text-only teleprinter costs about $1000, and an economical graphics terminal (Tektronix 4006) costs about $3000. Although many centers do not use graphics, the effective use of interactive computing for CAI may require graphics in the same sense that science and engineering classrooms have blackboards. The average hourly cost for these terminals will range from $0.08 to $0.24, compared with the $0.40 estimated for minis and micros.

Hardware Maintenance

The effective hourly maintenance cost per user station for micros may differ significantly from that for minis or maxis. Minis and maxis are sufficiently large and complex that most sites will decide to contract with an outside vendor for maintenance service ranges from 1 to 2 percent of the system's purchase price. For a timeshared minicomputer system, specialized for serving median-level instructional users, this charge is about $0.25 per hour of usage. For a maxicomputer system, the maintenance is included in the overall charges and may contribute roughly 10 percent to the total fee of about $5.00 per hour.

Microcomputers now available for stand-alone use are simple enough in construction that, for maintenance purposes, they can be handled much as if they were computer terminals. If an activity owns many identical units, it may be practical and economical for the activity to perform its own on-site maintenance. When a maintenance contractor comes to a customer's site, the usual approach is to isolate a problem to the level of a printed circuit board, and then to substitute a replacement board. For small computers, it is extremely rare for a repair of a circuit component to be attempted at the customer's site, or even at the contractor's local service office. More often, the faulty circuit board is shipped to a central service facility where a few specialists can work at maximum efficiency on a small repertoire of circuit boards. Some sites find it most economical to have a local technician deal directly with a national service facility, rather than paying the high costs of technicians employed by maintenance contractors.

To estimate the effective hourly cost for on-site maintenance of a set of 50 microcomputers, the following assumption is made: Micros are available from vendors who use (1) components of high quality, and (2) quality-control procedures, such that they are willing to warrant components to be free of failures for 1 year after installation. The usual approach is for the user's technician to request a circuit board replacement by telephone, with delivery to be made by air within 24 to 48 hours. The user returns the faulty board to the vendor, and no charge for this service is made within the warranty period. Vendors who use this approach have said that they expect 1 to 2 percent of their circuit boards to be returned during the 1-year warranty period, and much fewer thereafter.

Therefore, it is conservative to estimate an average component replacement cost amounting to 2 percent per year for each micro; that is, about $100. The technician cost is somewhat harder to estimate accurately. At U.C. Berkeley, one group of 80 terminals is serviced by a single full-time technician who deals with about one failure per day. Those terminals are subjected to heavy usage and some are mechanical teletypewriters, so the failure rate should be lower for a micro whose only mechanical components are a floppy disk drive and an electronic teletypewriter. On the average, the time required to correct a failure should be well under a day, usually no more than an hour or two. Therefore, one full-time technician should be able to service well over 100 micros, without having more than one or two machines out of action at any one time. To be conservative, assume that one technician, costing $20,000 per year, will be needed to service the set of 50 micros assumed in this estimate. The net annual cost for maintenance will therefore be about $25,000, or about $0.20 per hour of use. If the number of micros is larger, or if the technician works part-time on other duties, then the net cost per hour may be $0.10 or less.

Software

The cost of operating software (i.e., operating system, language processors, communication handlers) will usually contribute negligibly to hourly costs for the use of a maxi or timeshared mini, but may contribute significantly to the cost of using a set of micros. The current policies of major manufacturers of micros can lead to a software acquisition cost exceeding 50 percent of the hardware cost. Fortunately, this situation is likely to be corrected soon by charges in manufacturers' software pricing policies for micros, sharing of independently produced software, or both. It appears that the cost of software acquisition will contribute no more than $0.05 per hour to total operating costs for micros serving median-level instructional users.

Software maintenance is the term applied to the correction of errors in mature software. As noted earlier, several sites employ full-time system programmers to perform maintenance on the software used with timeshared minicomputers. There is a good possibility that the introduction of a small-message network would encourage collaboration among users, thus reducing the hourly costs for acquiring and maintaining software on minis and micros.

Miscellaneous Costs

Expendable supplies, particularly paper, have become a significant cost item for instructional computing at most sites. It is assumed that the median-level group of interactive users can be served adequately by using display terminals, which consume no paper supplies, and by providing a shared printer that can be used for occasional summary printouts.

Usually, the operation of a general-purpose computer center requires a sizable administrative staff. Whether or not personnel need to be assigned specifically for administration of a mini- or microcomputer learning facility is questionable. Even if no dollar charges are made for the use of interactive user stations, it will be necessary for someone to control the allocation of time. Allocation becomes a problem only when there are too few user stations to meet the needs of all students on uncontrolled schedules. Even in a class room with too few interactive user stations, it is possible to establish a set of allocation rules and to allow self-policing among the students. Either the technician or a user might be assigned part-time to the small number of administrative duties associated with equipment operation.

No estimates are made here for the cost of space, electricity, heating, or building maintenance. The environmental requirements of the micros are like those of the typical office or classroom. Accounting for these factors is typically not included in the prices charged computer centers. Maxicomputers require heavy air conditioning that is not generally needed for minis, and almost never for micros. Total energy consumption for the micros is likely to be less than the equivalent consumption for a maxi system plus terminals.

Total Costs

For the median-scale instructional user, the hourly cost for a general-purpose maxicomputer operated by an instructional computer center should be about $5.00. This figure is approximate, and may not include the estimated $0.08 to $0.24 covering the cost of heavily used interactive terminals. For the above-average user, the maxi will typically be the only way available. There are, and will continue to be, enough above-average users that every campus should continue to provide access to at least one maxicomputer. The income derived from median-level instructional users in a maxicomputer facility is rarely a very large proportion of the total income. This suggests that these users could be served much less expensively with micro- or minicomputers, provided that enough median-level users are available to justify acquiring the smaller equipment.

For the median-level instructional use of mini- or microcomputers, Table 1 presents a summary of estimated costs.

Table 1

Estimated Hourly Costs

Item	Micro	Mini
Hardware acquisition	$0.40	$0.40
Hardware maintenance	$0.10 - $0.20	$0.25
User assistance	$0.00 - $0.32	$0.32
Software acquisition	$0.00 - $0.05	----
Total	$0.50 - $0.97	$0.97

EQUIPMENT SPECIFICATION

Discussion

Maintenance

For large computer equipment, it is customary for a user organization to contract with the computer manufacturer or a third party for regular hardware maintenance and repair. For many new computer terminals, some organizations contract for maintenance services while others call in repair experts only when unusually difficult problems arise. The latter method seems to be preferred by organizations large enough to have many identical terminals in use, and thus able to employ a technician with sufficient training to make simple repairs. In fact, some universities and research laboratories find it possible to use staff technicians for all but the most difficult repairs.

Whether equipment is maintained under contract or by a staff technician, the approach to on-site repairs is generally the same. The technician first determines the general nature of the problem reported by the user and then traces it to a single printed-circuit board or mechanical component. The technician usually comes to the user's site prepared to install a new P-C board. For terminals and small minicomputers, the number of P-C board types in the customer's equipment is small, and the technician usually can bring a complete set. For larger minicomputers, the technician's office may first attempt to localize the problem by asking questions by phone so that the technician can take smaller selection of likely replacement components.

After a service call, the usual procedure is to ship the malfunctioning board to a central repair depot, often the manufacturer's plant. In some cases, regional repair centers have been established to reduce shipping delays. During the last several years, fast-turnaround airfreight service has become available in most U.S. cities at moderate prices (e.g., $20 for overnight delivery of a printed circuit board).

This situation leads to the observation that a large part of the cost of regular maintenance contracts for small computer equipment goes toward paying the travel and idle-time overhead associated with repair and maintenance technicians. Moreover, the technicians who work for the large manufacturers and maintenance firms are typically not expert on any single item of equipment, due to the need to service a very large variety of equipment and the need to minimize training costs. For a user organization that already employs electronics technicians for other purposes, lower maintenance costs and more effective service might be rendered by the user's staff technicians than by any contract maintenance organization.

Peripheral Devices

Extensive studies of the current marketplace for small computers leads to the conclusion that the lowest equipment costs are associated with designs in which as much as possible of the logic of connections to peripheral devices is handled in software by the central processor, or perhaps by an auxiliary microprocessor. The standard approach of the industry, for machines of the size and sophistication considered here, is still similar to traditional minicomputer design, in which each peripheral device required a separate, special-purpose interface module. Thees modules are expensive in themselves, and they require expensive supporting hardware. In many cases, the electronics needed to communicate between processor and peripheral device is effectively duplicated (e.g., the floppy disk drive and display unit for the stand-alone computer discussed in this report).

Add-in hardware for interfacing with peripheral devices or for additional memory often is available from independent contractors, who compete with the principal manufacturer of the processor itself. The prices for the add-in equipment tend to be set by the processor manufacturer, whereas independents may charge 15 to 20 percent less. Several small, independent manufacturers have said that they earn a very high mark-up for equipment priced this way. Although it has been pointed out to several independents that less expensive interface and controller modules for peripheral devices could result from combining the control functions for several peripherals on a single printed-circuit board, such innovation is unlikely because most independents can maximize their profits by selling equipment that competes with the conventional lines offered by major manufacturers. Moreover, the major manufacturers have a longer product-design cycle and seem to be innovating only as fast as necessary to reduce prices at a moderate rate. The marketplace is not yet demanding a faster rate of introduction of the less expensive, more highly integrated components.

Quality

A large amount of low-priced, small computer equipment is now being offered to hobbyists. It is possible to configure complete systems for the purposes described here for less than $5000 per unit, but such equipment is unsuitable for computer-based instruction or most offices. Some hobbyist-grade equipment is being used successfully to teach college students about the design of digital systems that use microprocessors and, in that environment, an occasional equipment breakdown may enhance the teaching effectiveness of a course. The industrial-grade equipment offered on the original-equipment manufacturer market are only slightly more expensive than the hobbyist-grade equipment, and the saving in maintenance costs should be well worth this higher initial price.

Minimum Specifications for a General-Purpose, Educational, Stand-Alone Computer

The small computer system specified here is to be used for interactive instructional computation supporting large classes. It will be used primarily in a "stand-alone" mode, serving one user at a time for interactive applications. Occasionally, it will be used as an "intelligent" communications terminal. The computer will not be used for timesharing.

Processor

The processor (1) must be object-code compatible with the Digital Equipment Corporation LST-11 microcomputer, (2) must be capable of running any software developed for the LSI-11 without alteration, and (3) must provide an optional hardware multiply/divide feature that is object-code compatible with the LSI-11. The vendor must guarantee that no legal constraints prevent the use of licensed Digital Equipment Corporation software on the specified system, if desired by the user.

Main Memory

The main memory must contain 28K 16-bit words of semiconductor memory (may include 4K words on LSI-11 board).

Floppy Disk

The floppy disk must have a standard IBM-compatible, soft-sectored Flexible Disk drive (128 bytes per sector, 256K bytes per disk). One drive is required, and at least a second-drive option must be available. The floppy disk interface must be software-compatible with the Digital Equipment Corporation RT11 operating system. The floppy disk drive must employ a ceramic read/write head or another head design with equivalent or better reliability characteristics. The floppy disk drive module must be mounted in such a way that minimally trained, nontechnical personnel can replace a drive for maintenance purposes.

Display Unit

A CRT or plasma panel display unit must be provided that can handle both alphanumeric text and "bit-map" graphics information. The screen must measure at least 9 inches diagonally. When displaying only text, the screen capacity must be at least 24 lines of at least 80 characters each, using, as a minimum, the standard 96-character ASCII character set. When displaying graphics, resolution must be at least 240 points high by 320 points wide, with preference given to designs offering equal bit densities both horizontally and vertically. Means must be provided to display a "cursor," or equivalent pointing device, at any point on the screen in both modes under software control. Means must also be provided to allow software to erase displayed items selectively (without the need to erase the entire screen and then redisplay portions not logically erased). In the alphanumeric mode, the display speed must be at least 960 characters per second, and scrolling must be possible, both upward and downward, within an alphanumeric window. In the graphics mode, each displayed bit must be set or reset selectively by software without affecting other displayed bits. The maximum allowable time to set or reset one bit in display memory will be 100 microseconds using an assembly language subroutine in the main processor. If a standard television monitor is to be used, then the refresh rate must normally be 60 per second with a P4 or equivalent persistance phosphor. Otherwise, if the refresh rate is to be 30 per second, then a P39 or equivalent persistence phosphor must be used.

Keyboard

A keyboard must be provided, mounted in its own free-standing enclosure, and connected to the processor via a cable at least 6 feet long. Characters must include at least the full 96-character ASCII set. Special function keys must include four directional arrows (up, down, right, left) intended for positioning the cursor, plus the standard ASCII control codes for Space, Carriage Return, Backspace, Escape, Break, and Delete. Means must be provided to allow the automatic repetition of any key when depressed for longer than about one-half second or when a special "repeat" key is depressed.

Communication Interface

A standard RS232-C communications interface must be provided, via an EIA standard 25-pin female connector, in addition to any connection needed for the display and keyboard units. The interface must be arranged to handle any standard signaling speed, including 110, 300, 1200, 2400, 4800, and 9600 bits per second. Preference will be given to a design using a switch, rather than wired jumpers, to make the speed selection. The option must be available for the user to purchase a second communication interface of the same type specified here.

Housing and Power Supplies

The computer and associated electronics must be housed in a table-top cabinet containing power supplies for 115 VAC distribution systems, any necessary cooling system, control switches, and all other devices to make a complete, self-contained system. The appearance of the cabinet must be compatible with a classroom or office environment. Preference will be given to a design with blower noise less than or comparable to the noise levels of current CRT display terminals. Power supplies and all other electronics must be able to survive momentary power failures without permanent physical or electrical damage. If the equipment is supplied in more than one cabinet, then similar specifications apply to all cabinets.

Maintainability

Preference will be given to designs that make it practical for a minimally trained, nontechnical user to swap malfunctioning printed-circuit boards for working spares. Preference will be given to vendors who warrant board-level modules to be free of defects for at least 1 year after the equipment is delivered, and who will deliver (free of charge within the warranty period) replacements within 24-48 hours upon notification that a malfunctioning part has been discovered by the user. Software to allow the user to diagnose faulty components under reasonable conditions must also be provided. The vendor must offer optional on-site maintenance services under contract, using either the vendor's own personnel or a third-party maintenance contractor.

Optional Extensions

The specified system must be so designed that users may purchase optional interface modules to allow connections to a variety of auxiliary equipment.

CONCLUSIONS

A portable microcomputer system powerful enough to be used for interactive instructional applications is currently available for about $5500. The machine is capable of running a variety of higher-level languages and other complex software, such as a CRT-oriented word processing system. It has a random-access, second-level storage medium; a CRT display unit that can handle both text (24 lines of 80 characters) and graphics (resolution of 240 by 320 points); and 28K words of memory. The machine runs a nearly machine-independent operating system, USCD PASCAL, so software developed on this machine can readily be moved to less expensive and more powerful microcomputer systems as they become available.

RECOMMENDATIONS

Because of their low cost and their ability to be deployed at remote sites, portable microcomputer systems should be further investigated as a means of delivering instruction. Specifically, high-priority Navy training applications should be identified in which an on-site or nonschool training capability is an important option. The feasibility of using microcomprocessor terminals to deliver such instruction should be tested.

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